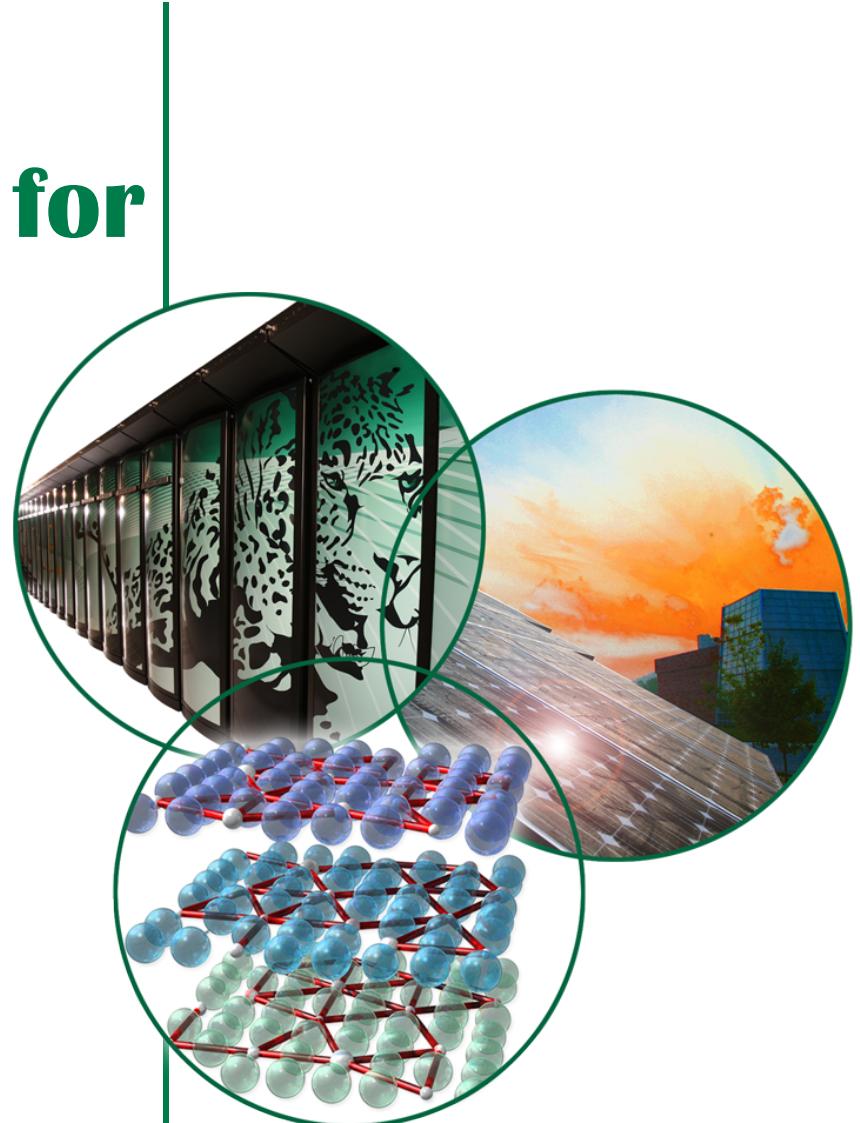


SCALE Developments for Criticality Safety

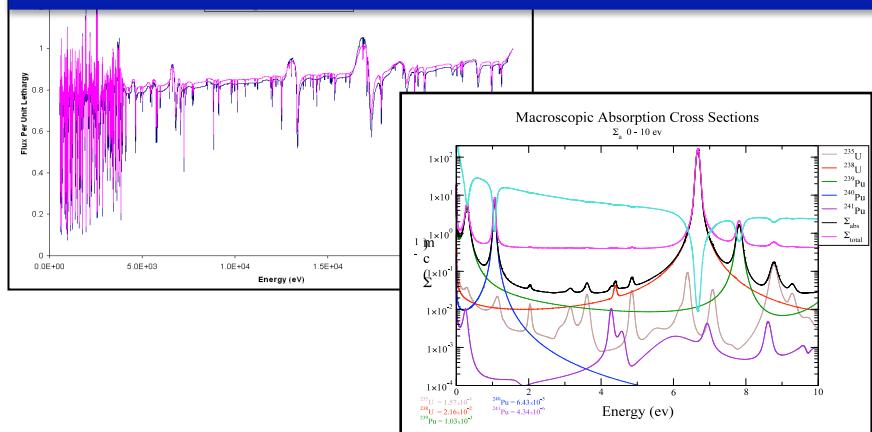
*Nuclear Criticality Safety Program
Technical Seminar*

March 1, 2011

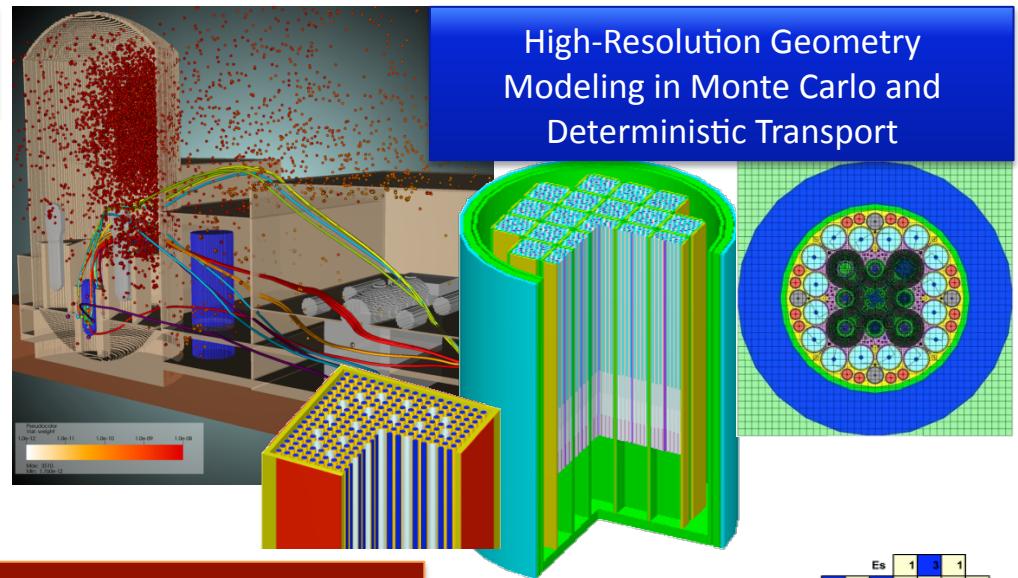
**Brad Rearden
SCALE Project Leader
Reactor and Nuclear Systems Division**



Current Nuclear Data Libraries with Continuous-Energy Resonance Processing

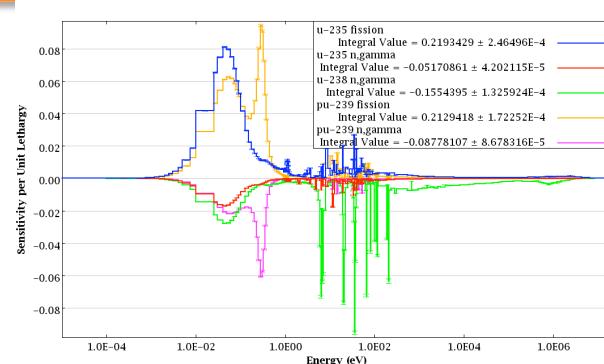


High-Resolution Geometry Modeling in Monte Carlo and Deterministic Transport



SCALE Capabilities

- Criticality safety
- Radiation shielding
- Cross-section processing
- Reactor physics
- Sensitivity and uncertainty analysis
- Spent fuel and HLW characterization

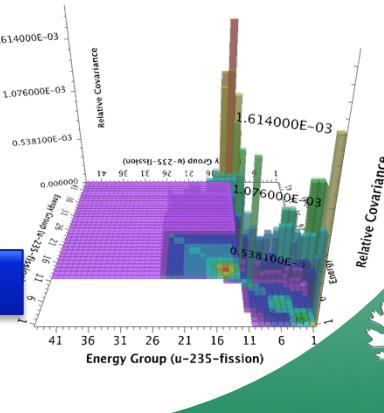


Sensitivity and Uncertainty Analysis

SCALE Developments for Criticality Safety

Es	1	1	1		
Cf	0	1	3	1	1
Bk	1	1	1	1	1
Cm	1	3	3	3	3
Am	1	1	3	3	1
Pu	1	1	2	3	2
Np	1	1	3	3	1
Pa	3	1	1	1	1
Th	1	1	3	1	1
Ac	1	1	1	1	1
1	1	1	1	1	229
1	1	224	225	226	227
1	220	221	2		
1	219				218

Depletion and Decay, Radiation Source Terms, and Decay Heat



OAK RIDGE
National Laboratory

SCALE 0.0 – SCALE 4.4a

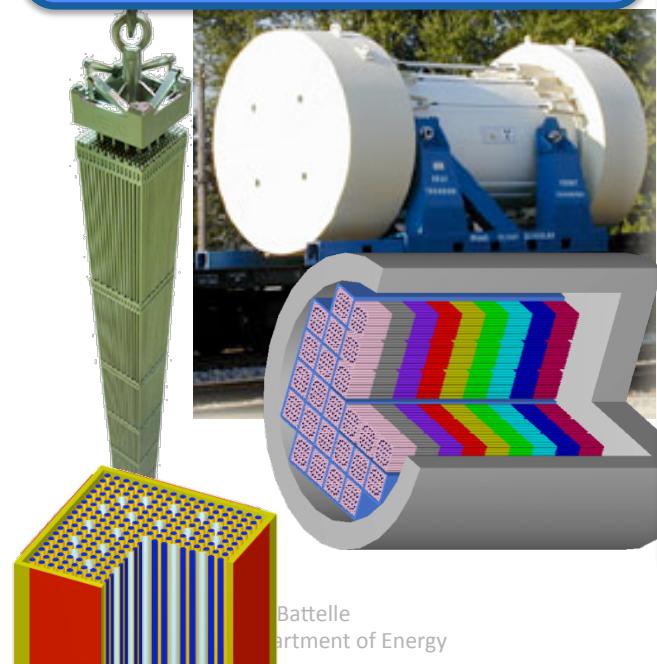
1980 – 2000

Established for Nuclear Regulatory Commission

Provides an independent rigorous nuclear safety analysis capability for out-of-reactor license reviews

Key Capabilities

- Criticality safety
- Radiation source term characterization
- Radiation shielding
- Heat transfer



Battelle
Department of Energy



SCALE 5.0 – SCALE 6.1

2004 – 2010

Expanded Capabilities to Address a Broader Class of Problems & Sponsors

- Reactor physics
 - Shielding analysis with automated variance reduction
 - Sensitivity and uncertainty analysis
 - High-fidelity criticality safety in continuous energy
 - Graphical user interfaces and visualization tools
- Expanding Use**
- Used in 40 nations by regulators, vendors, utilities, and researchers

SCALE Developments for Criticality Safety

SCALE 6.2 – SCALE 7.0

2012 – 2014

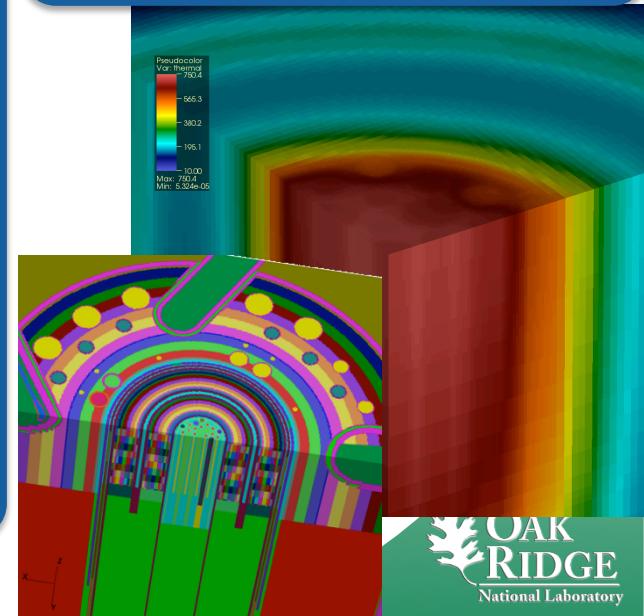
HPC Integration, Architecture Modernization, Further Expansion of Capabilities

Solutions for extremely complex systems

High-fidelity shielding, reactor physics and sensitivity analysis in continuous energy

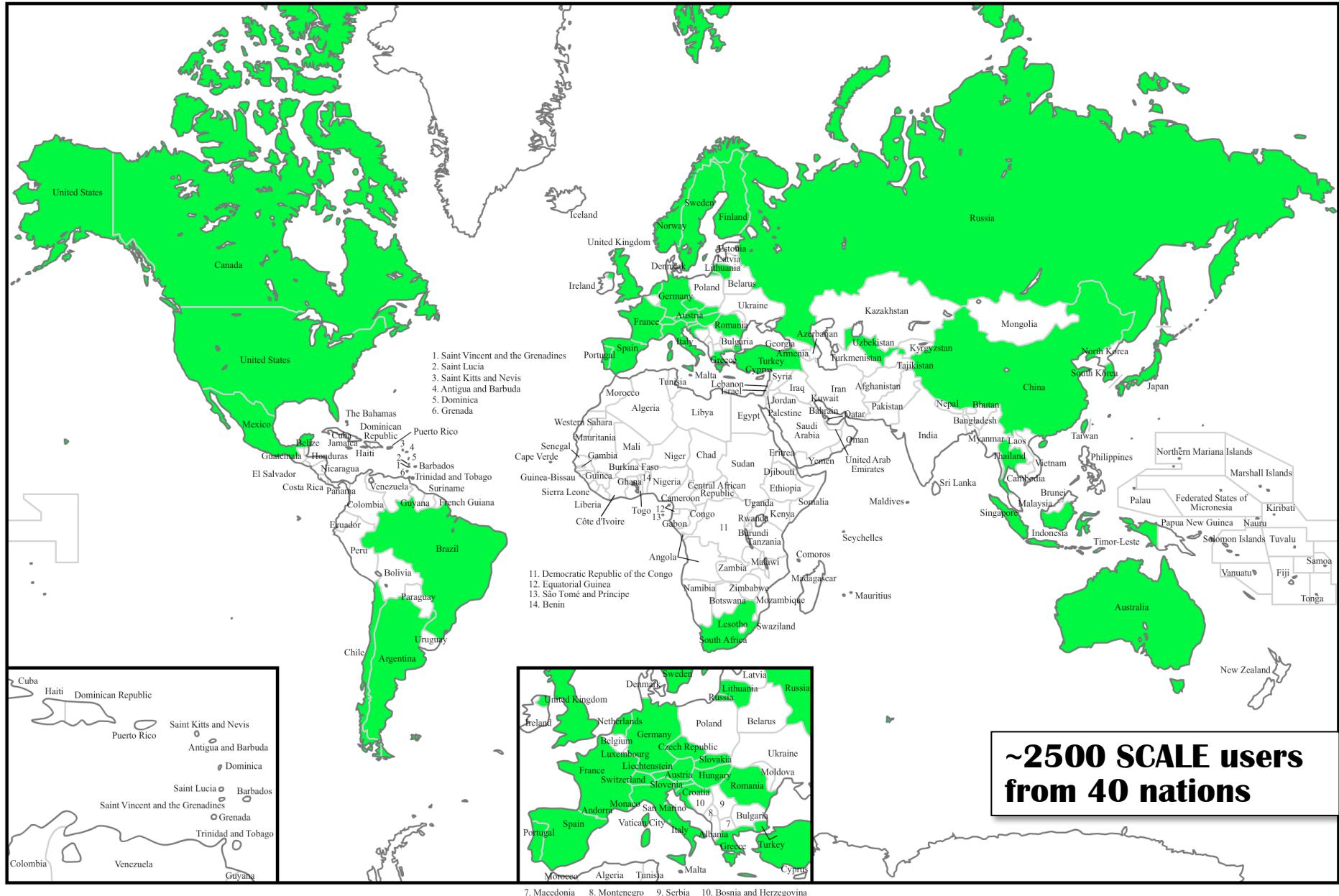
Scalable from single core PCs to massively parallel machines

Integration with CASL Virtual Environment for Reactor Analysis



OAK RIDGE
National Laboratory

SCALE Map of the World





Pacific Northwest



IRSN



Managed by UT-Battelle
for the U.S. Department of Energy

SIEMENS

SCALE Users
Regulators
Industry vendors
Utilities
Research laboratories
Government agencies
Universities



cea

A
AREVA

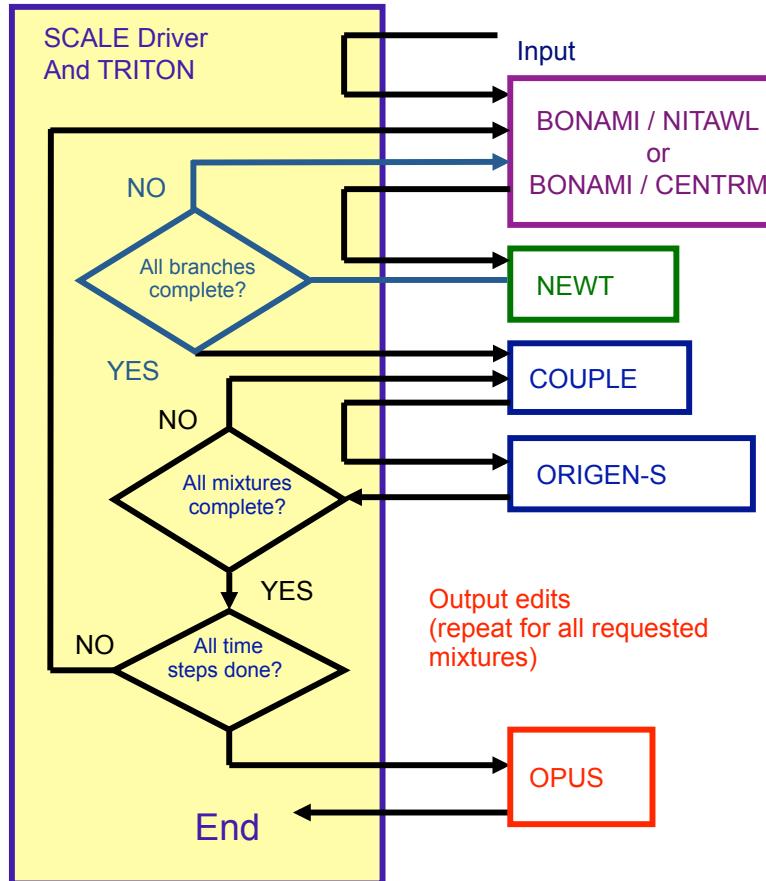


GRS



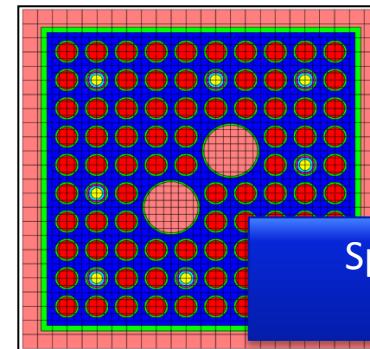
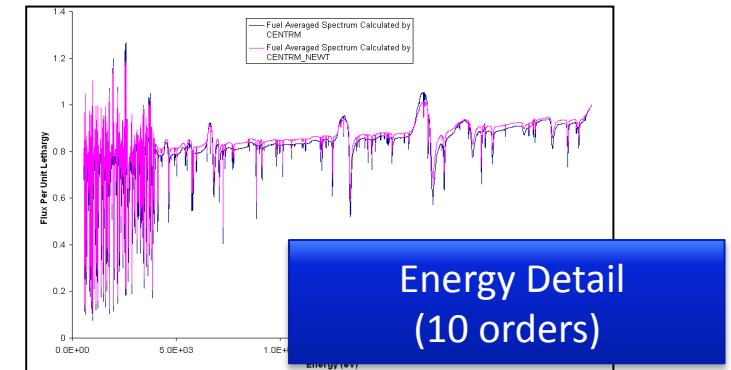
SCALE Developments for Criticality Safety

SCALE is Built on a Modular Design

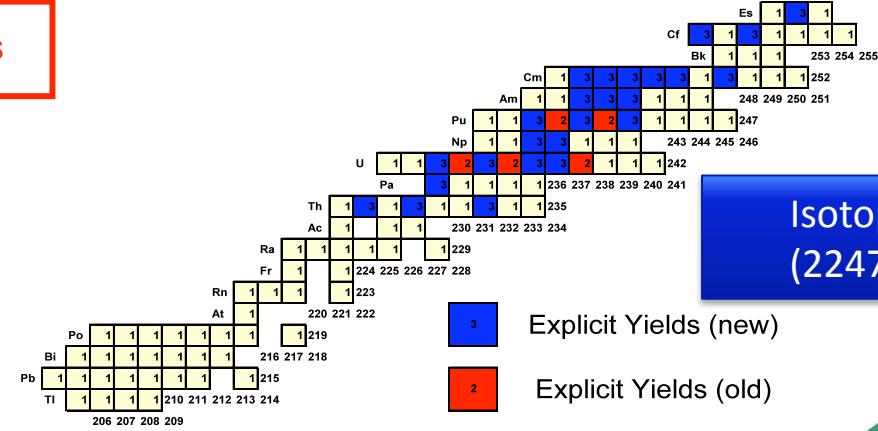


SCALE 6.1

- 89 computational modules
- ~1,000,000 lines of code
- Fortran/C++/C/Java
- 17 GB of nuclear data



Spatial/Angular Detail
(5 orders)

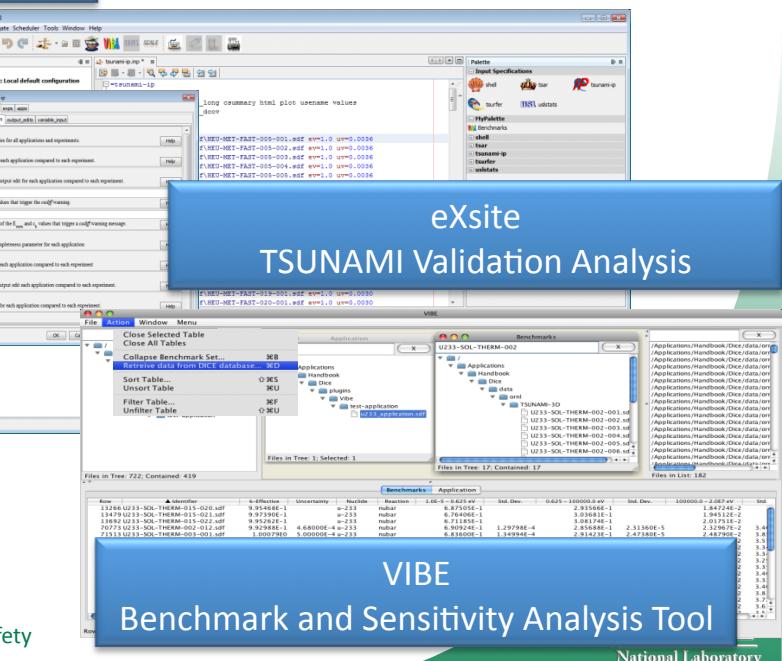
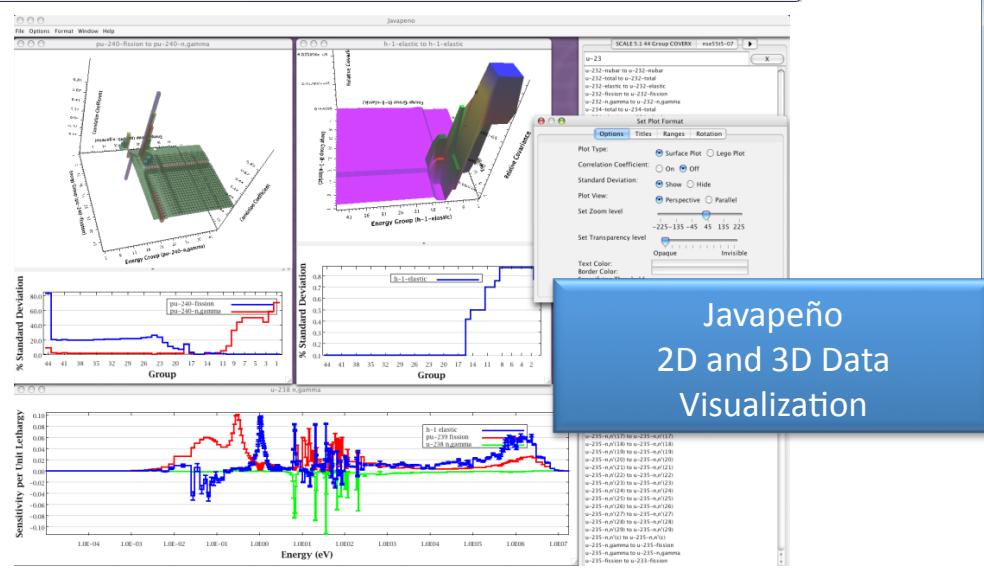
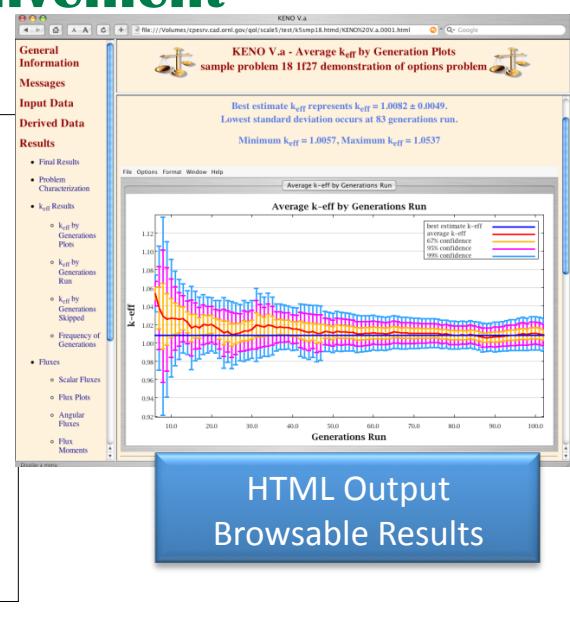
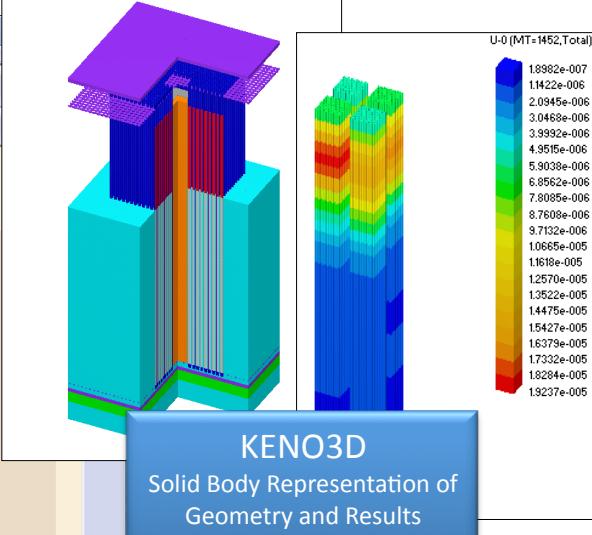
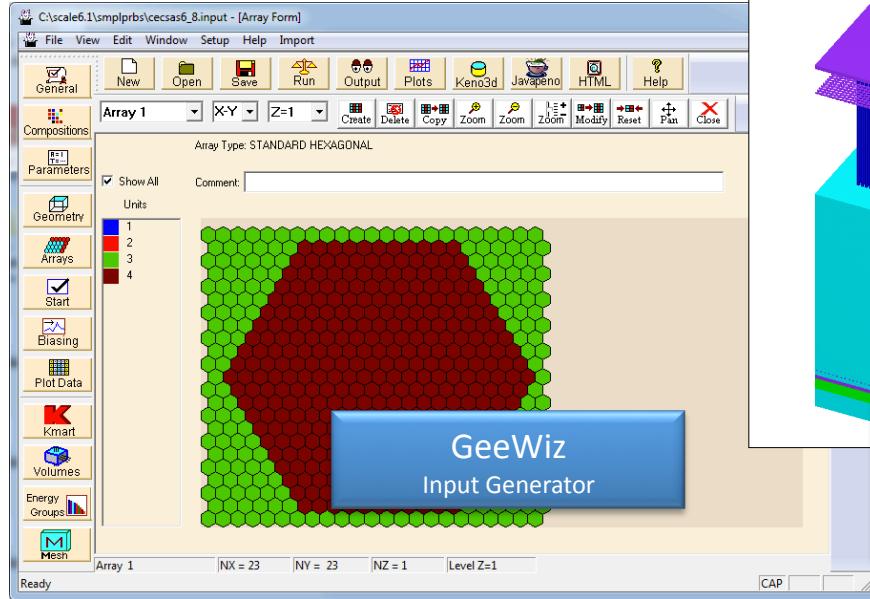


Isotopic Details
(2247 nuclides)

Explicit Yields (new)

Explicit Yields (old)

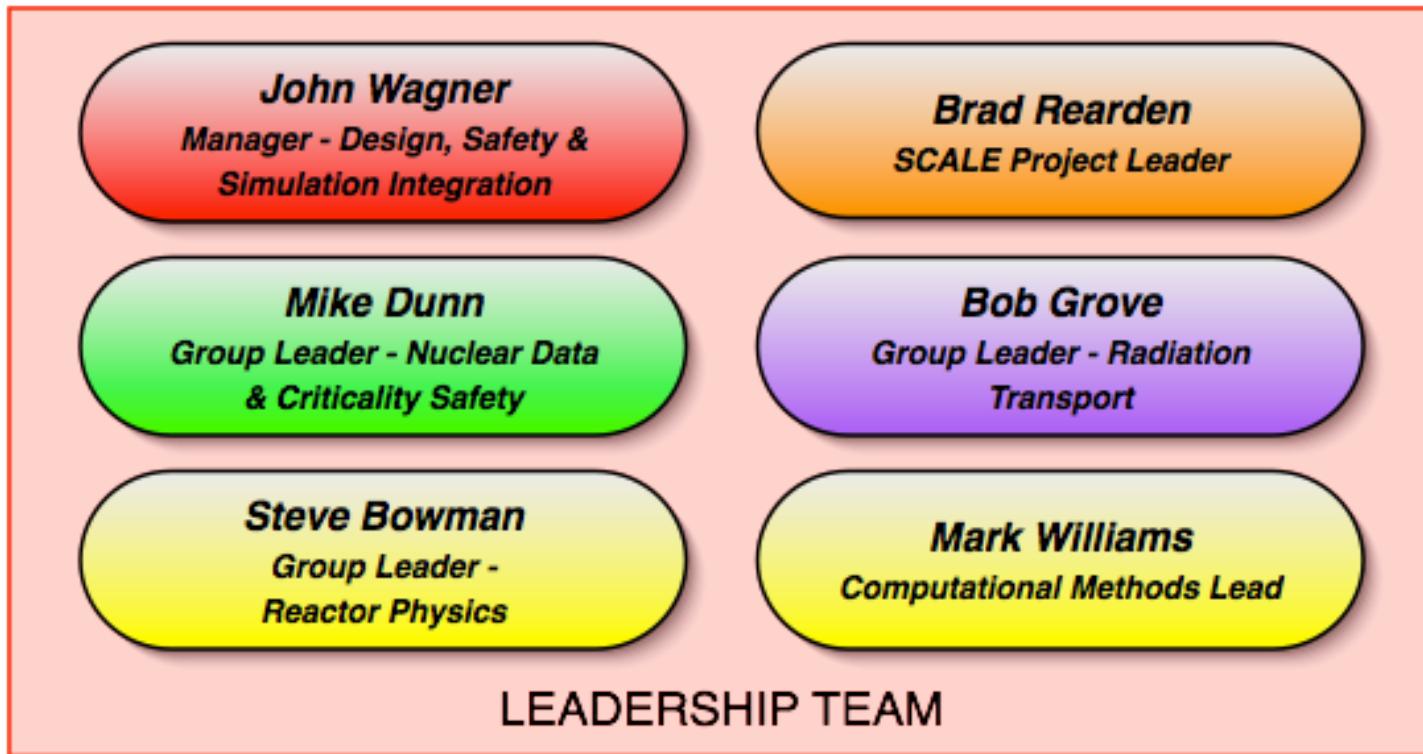
SCALE's Graphical User Interfaces Provide Convenient Input Generation and Output Interpretation



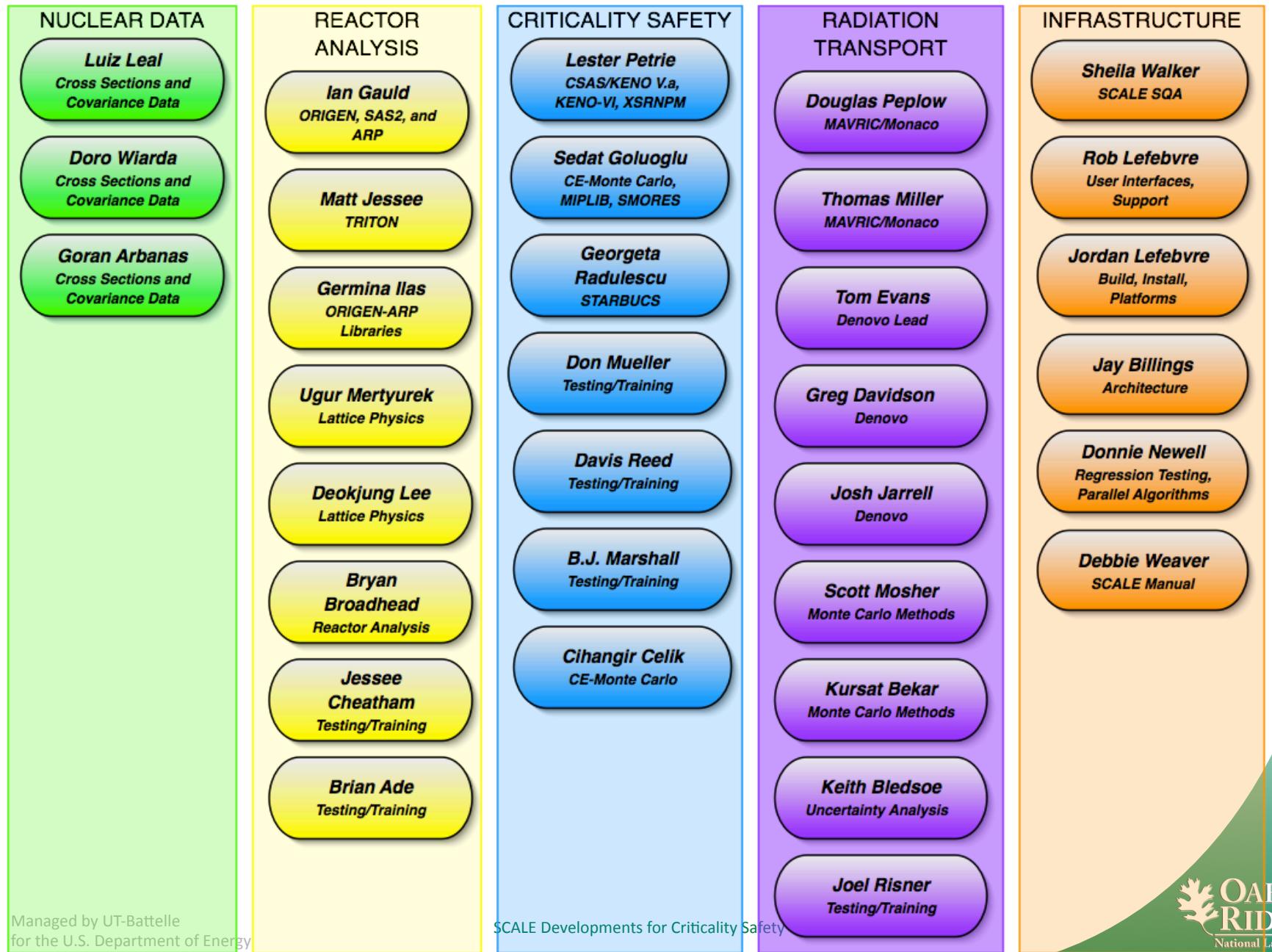
VIBE
Benchmark and Sensitivity Analysis Tool

National Laboratory

SCALE Staff – Leadership Team

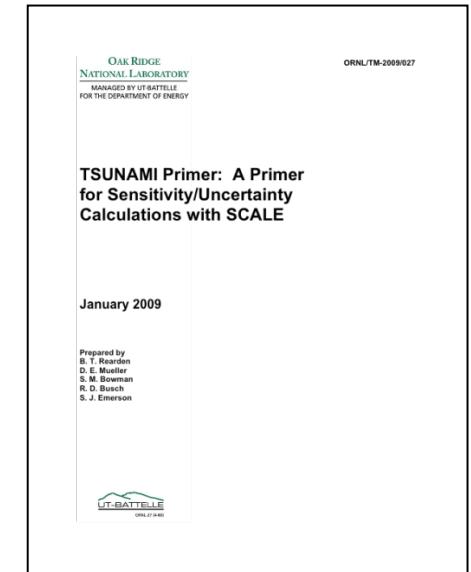


SCALE Staff (con't)



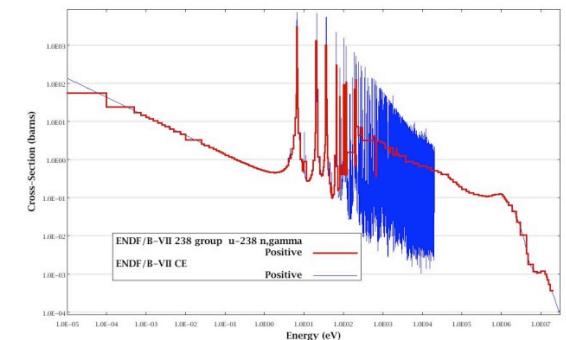
Training and User Assistance

- **Training Courses**
 - ORNL Courses: 4-week blocks presented twice per year
 - 10-20 attendees for each week
 - Other courses: DOE sites, OECD, IAEA, and user facility training typically presented 2-4 weeks per year
- **Workshops**
 - Presented free of charge at conferences around the world
- **Primers**
 - Several “getting started” guides on specific topics
 - Used as NCSET Modules
- **SCALE Web Site (scale.ornl.gov)**
 - SCALE Newsletter - current and past issues
 - SCALE User Notebooks (FAQs)
 - Validation and benchmark reports
 - Download updates
- **User help available**
 - scalehelp@ornl.gov
 - hundreds of issues addressed each year



SCALE Tasks

- Maintenance – ongoing activity
 - Software quality assurance and testing
 - Bug fixes, minor feature enhancements
 - Supporting new hardware, operating systems, compilers
 - General user support
 - Newsletter
 - Website
- Development
 - Targeted feature requests
 - Typically initiated by a sponsor or end-user need
 - Milestone detailed by sponsor
- Nuclear Data
 - Maintenance of nuclear data generation capabilities
 - Development of updated nuclear data libraries



SCALE Tasks (continued)

- **Technical support**

- Provides access to ORNL/SCALE staff as subject matter experts, especially for investigating or resolving technical and licensing issues related to criticality safety, dose assessment, or reactor physics
- Reviewing technical submissions
- Participation in standards committees and expert groups

- **Training**

- Support for public classes on SCALE
- Support for targeted private classes on SCALE

- **Application Studies**

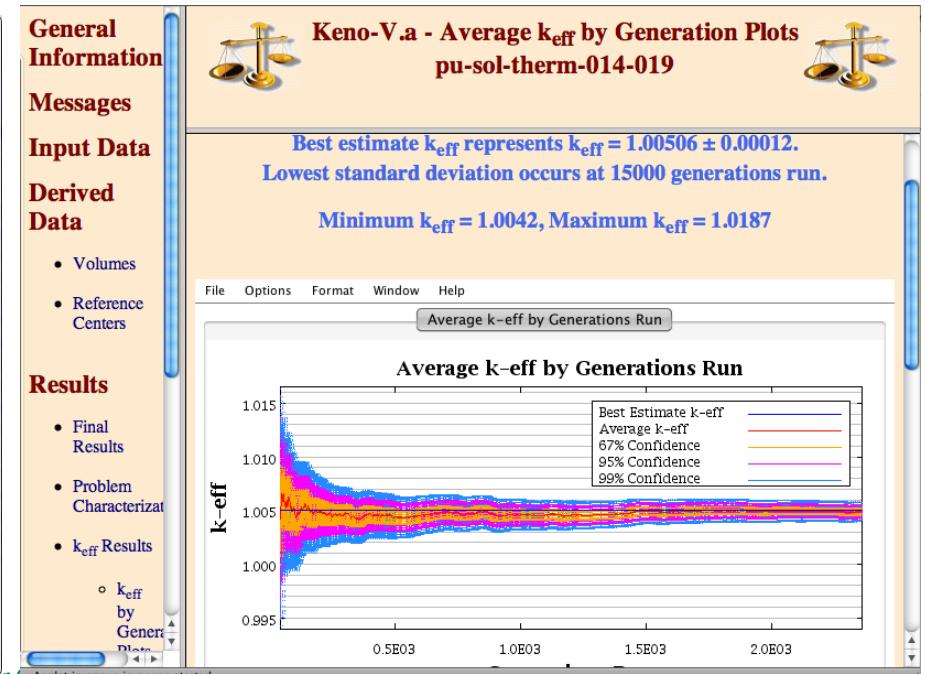
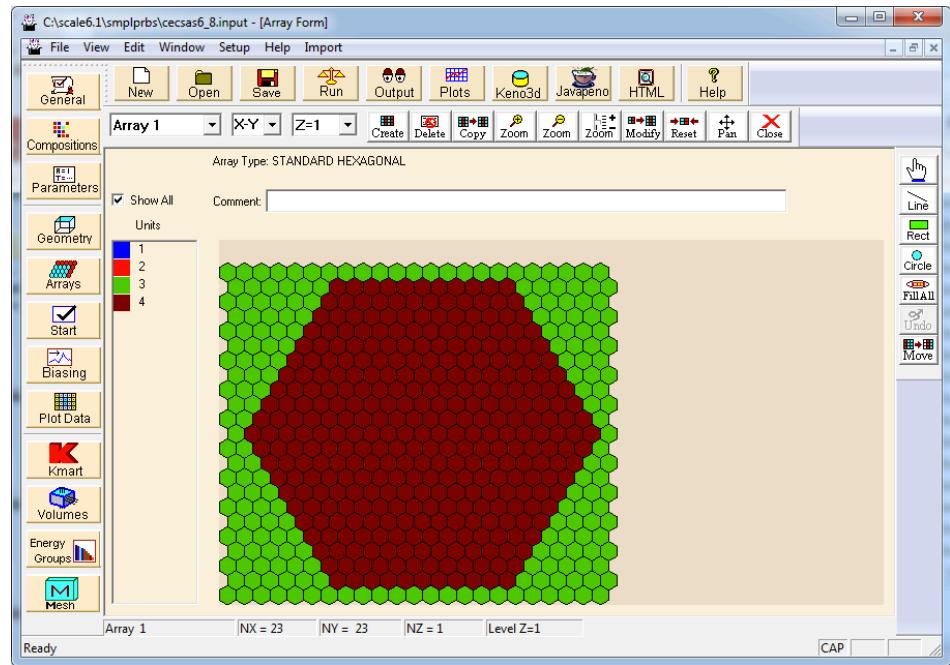
- Specific, typically advanced, studies with SCALE
- Applications often drive future development

Development Cycle and Quality Assurance

- **Quality is a top priority, and an extensive quality program is used to govern the development and deployment process.**
- **Quality Assurance Program**
 - SCALE QA plan is under revision for compliance with DOE 414.1C, NQA-1, and ISO 9001.
 - Current QA document is ~95% compliant and QA activities are compliant.
- **Tested versions of SCALE are provided to RSICC for public release.**

KENO Monte Carlo for Criticality Safety

- 40-year history of Monte Carlo calculations for criticality safety analysis
- Ongoing development and maintenance assures best-available techniques for end users
- Multi-group and continuous-energy
- Integrated input GUI
- Visual HTML output format



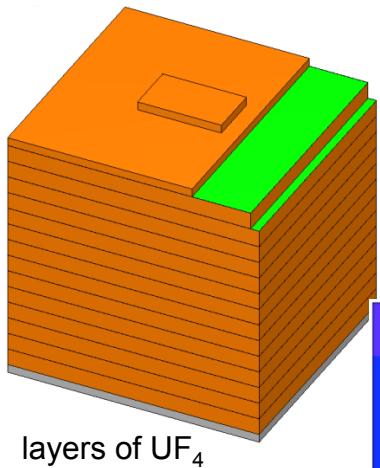
TSUNAMI

Tools for Sensitivity and Uncertainty Analysis Methodology Implementation

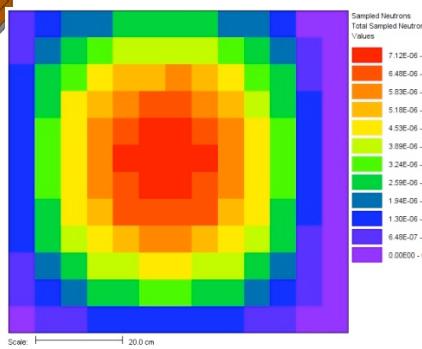


- Monte Carlo neutron transport sensitivity analysis tool for accurately modeling complex geometries
- Comprehensive library of cross-section covariance data
- Identification of important contributions to criticality and computational biases
- Quantification and extension of area of applicability for benchmark experiments
- Advanced bias assessment techniques
 - TSURFER Data Adjustment techniques
 - Nuclide-specific, energy-dependent biases, detailed bias uncertainties, gap analysis
- Means to use benchmark data in ways not previously available
 - Extraction of data from replacement experiments
- Design of experiments to meet targeted needs
 - required step in C_edT process

SCALE CAAS Capability

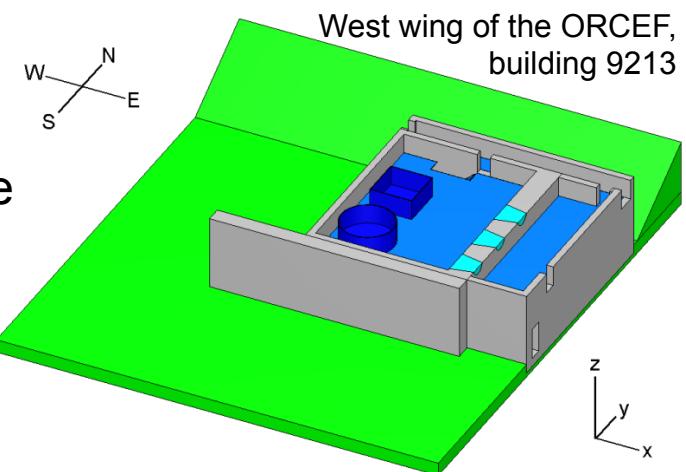


layers of UF₄

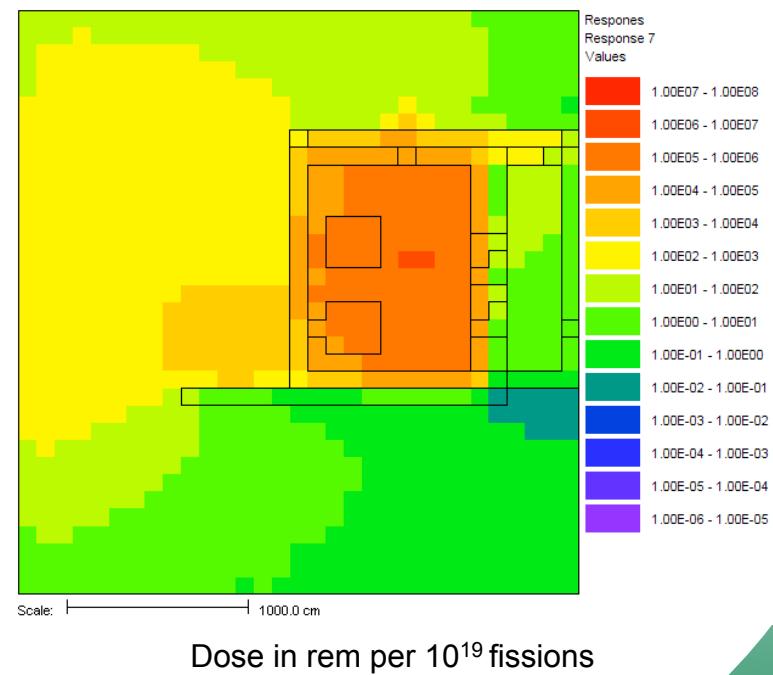


Step 1:

- Use KENO-VI to model the criticality accident and save the fission distribution as a mesh source



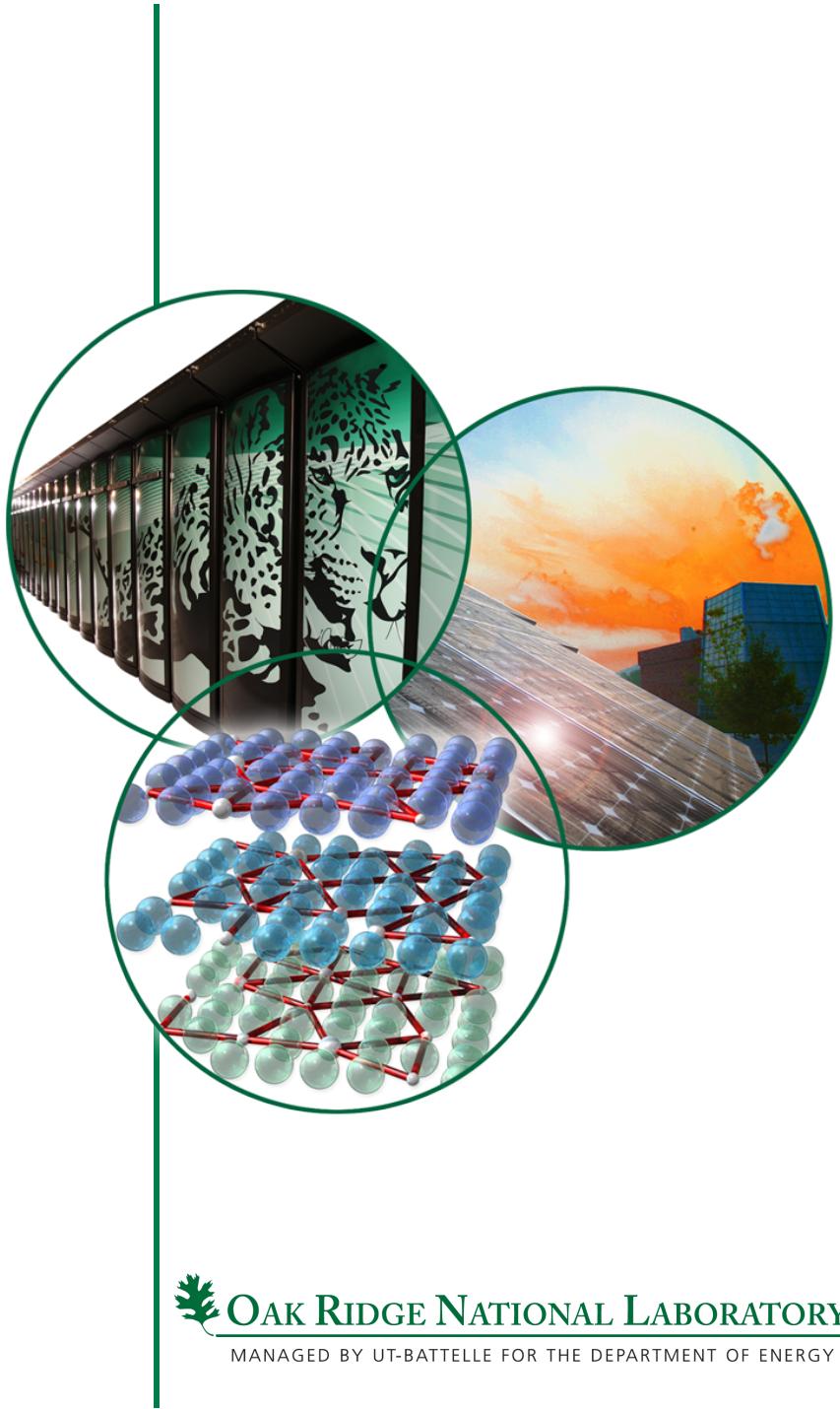
West wing of the ORCEF,
building 9213



Speedups of 3000 to 4500

Enhancements in SCALE 6.1

Focus on quality and ease-of-use



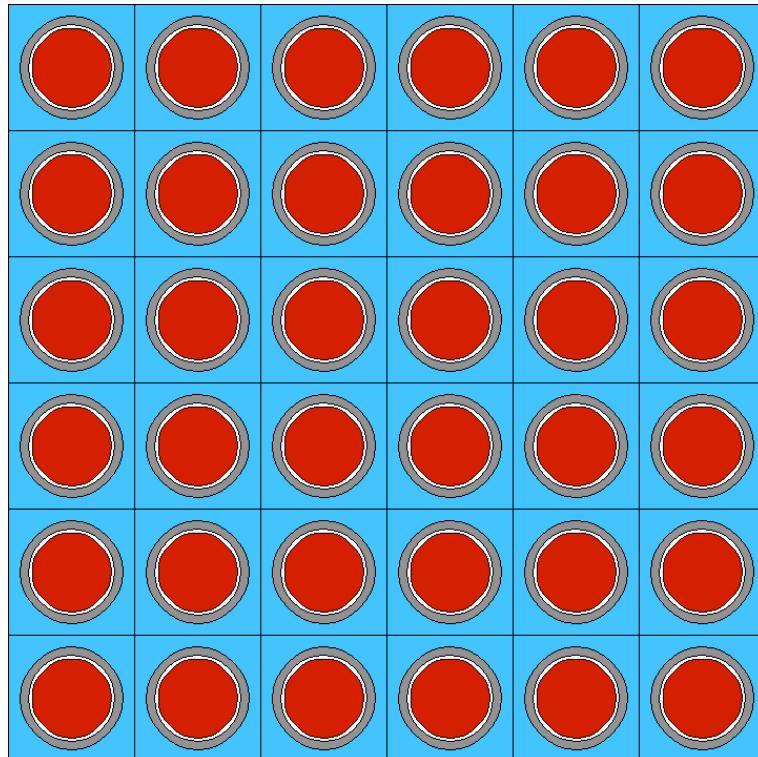
Criticality Safety

- **KENO**
 - Easier mesh specification
 - Improved mesh volume calculation
 - Improved mesh output edits
 - Region mean free paths in CE KENOs enabled
- **Fission source distribution output**
 - For CAAS or visualization
 - MG/CE, KENO V.a/KENO-VI
 - Exported in .3dmap format with uncertainties

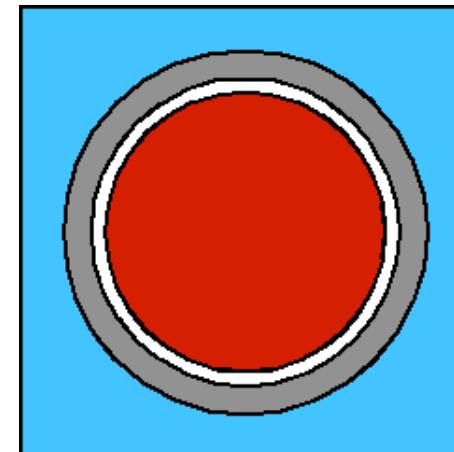
KENO Mesh Accumulator

- For TSUNAMI, forward and adjoint fluxes are accumulated over same mesh, then multiplied together prior to summing over a region (e.g. all fuel pins).
- Volume of each material within each mesh region is required.

Array Without Automated Mesh

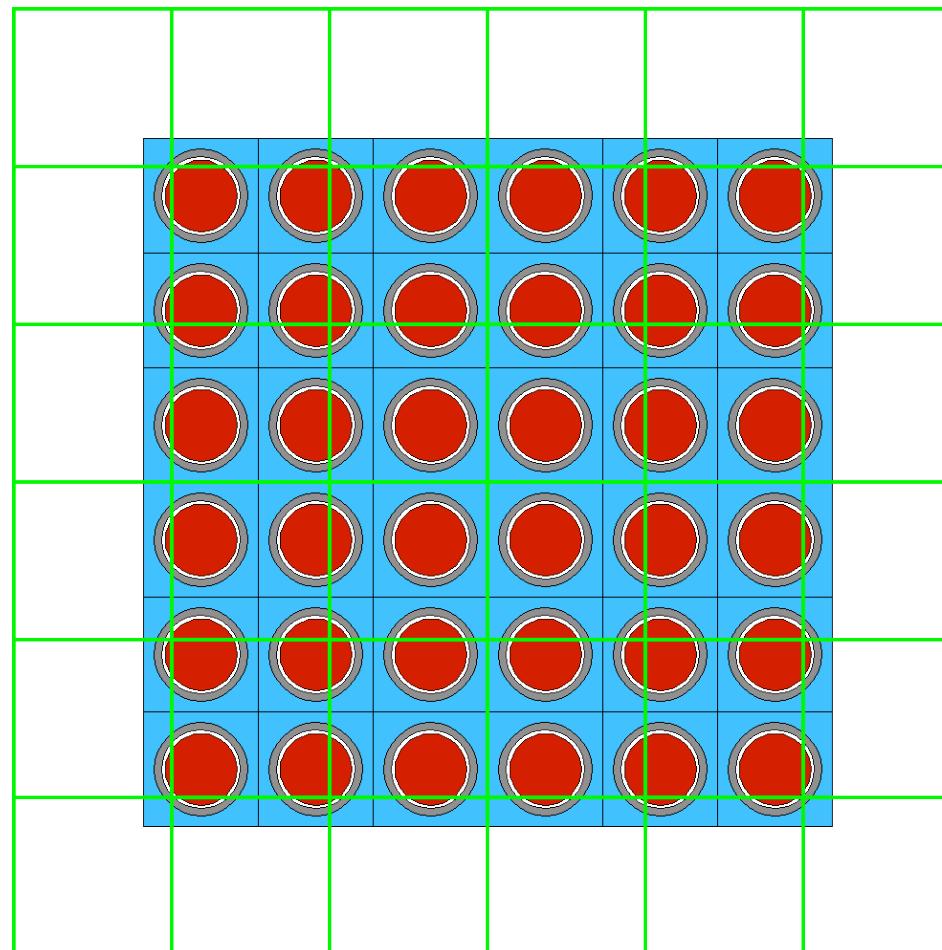


6×6 Array of 4-region cell
for 144 regions

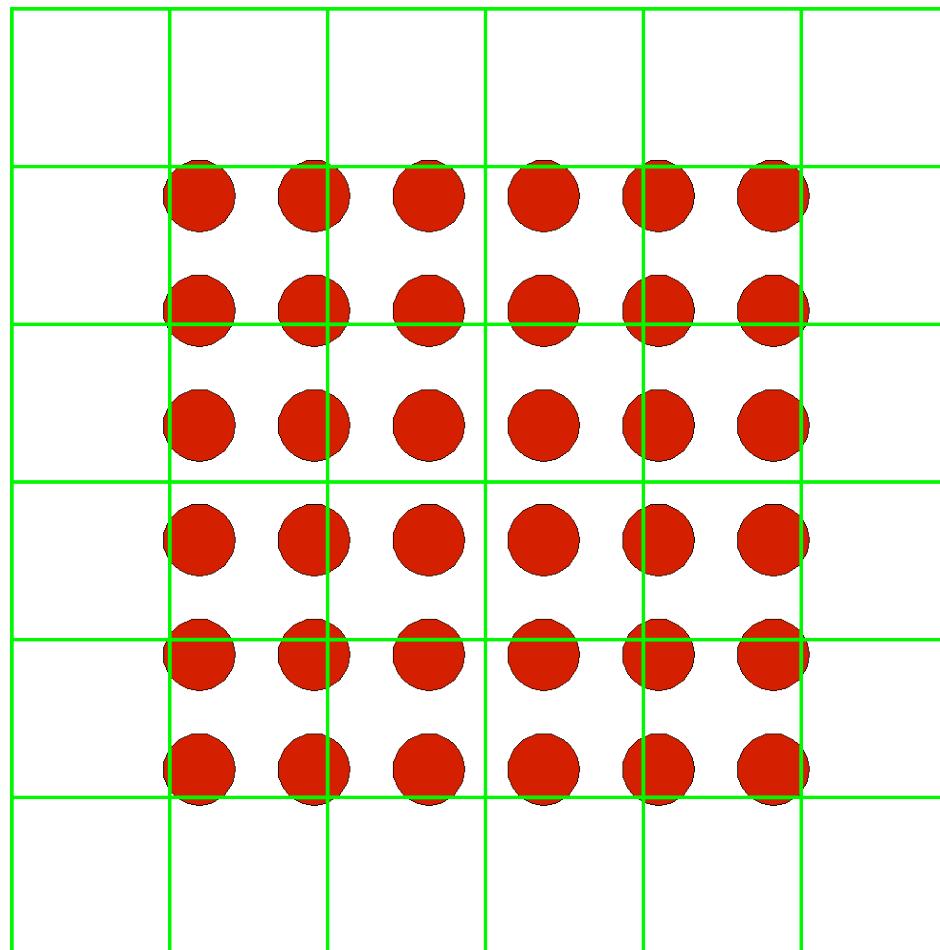


4 flux regions
fuel, gap, clad, mod.

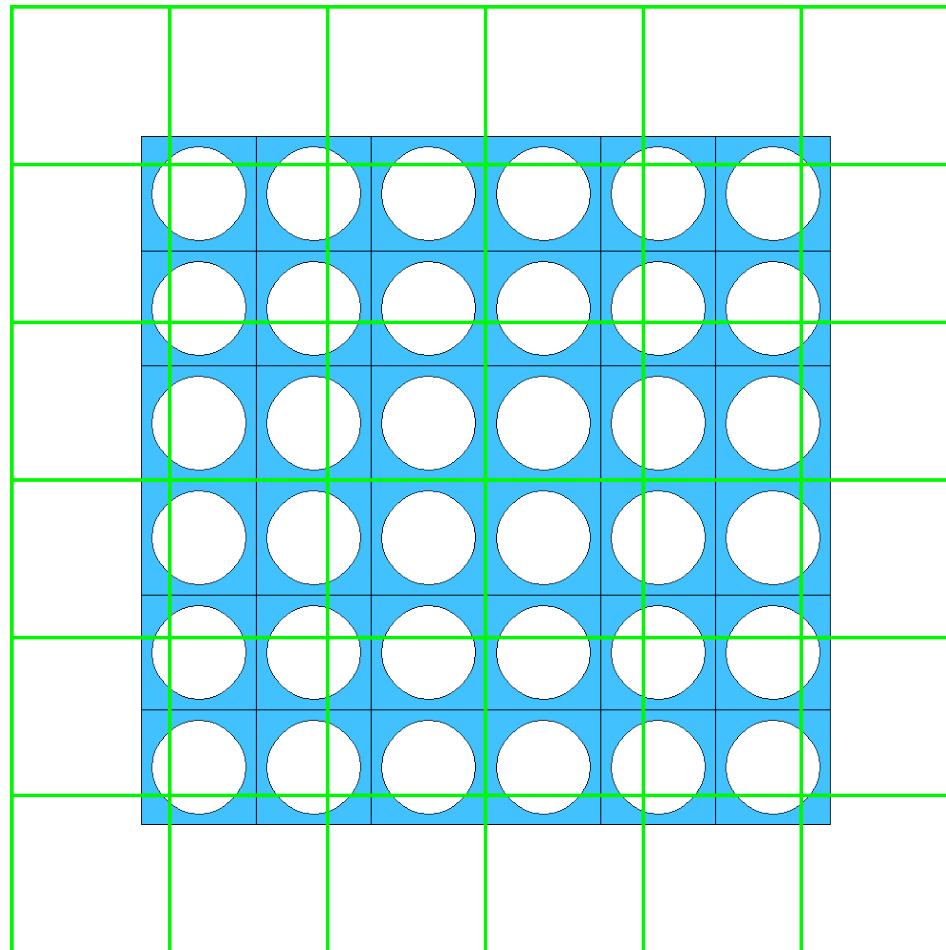
Automated Mesh (1.375 x pitch)



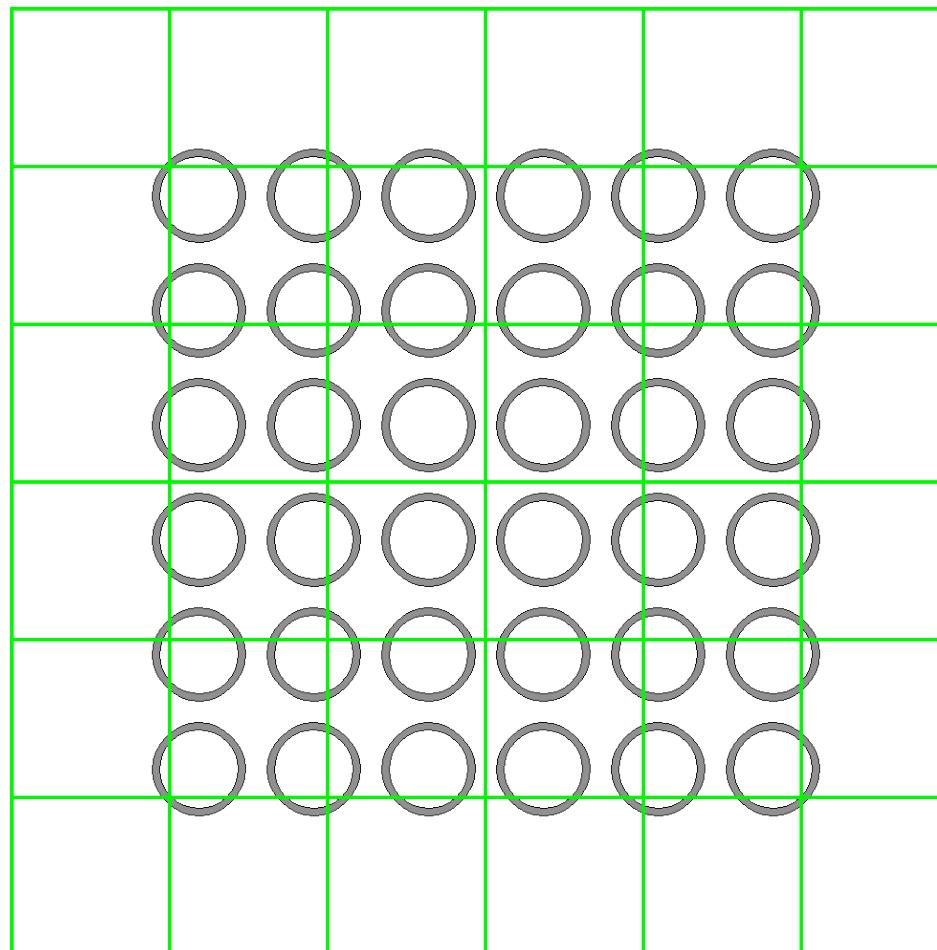
Automated Mesh Fuel Regions



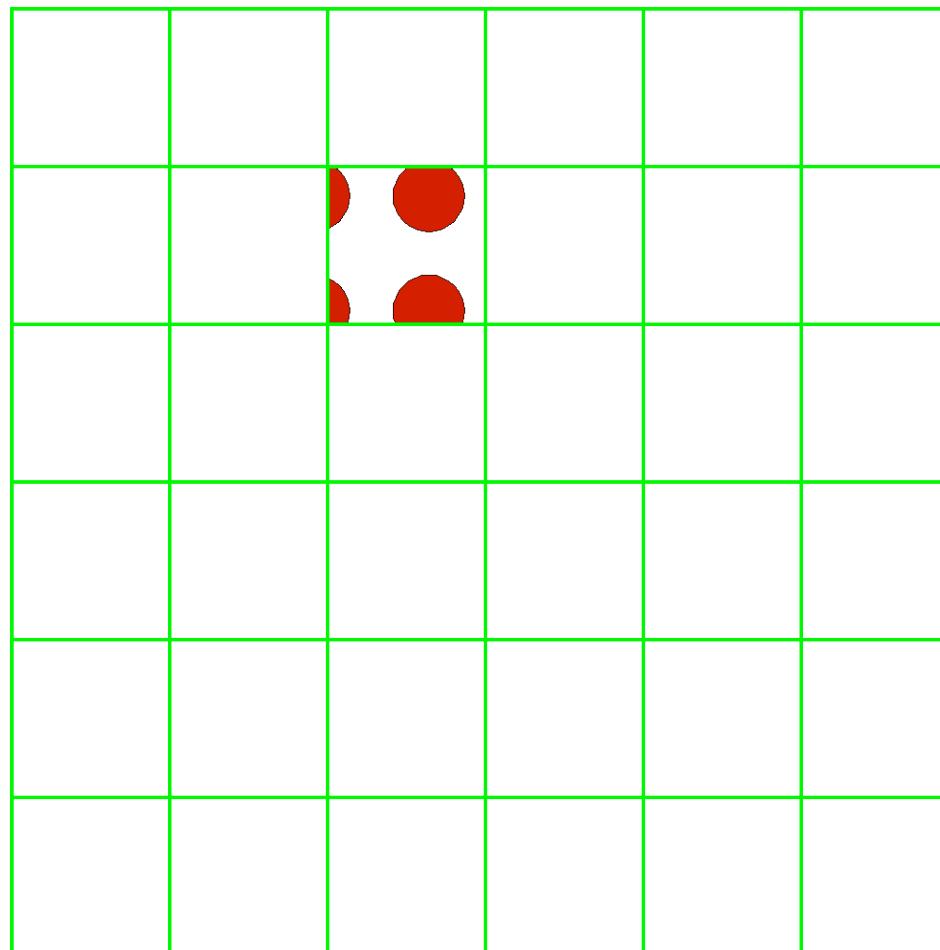
Automated Mesh Moderator Regions



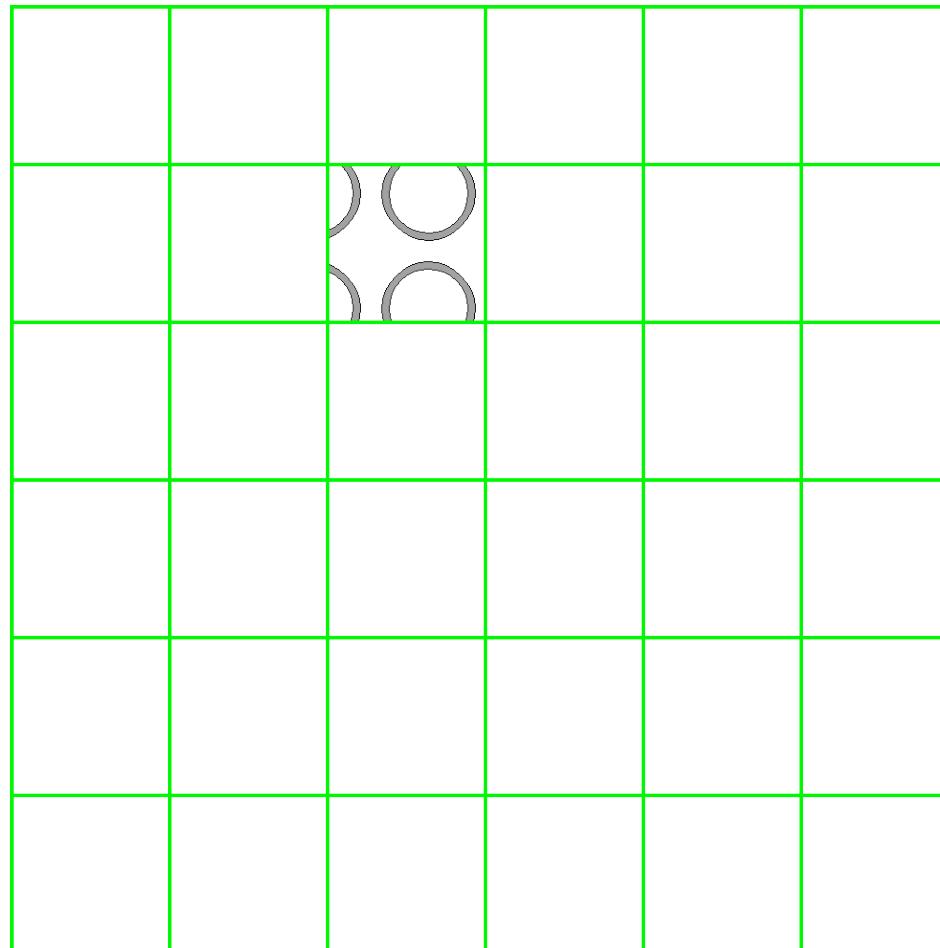
Automated Mesh Clad Regions



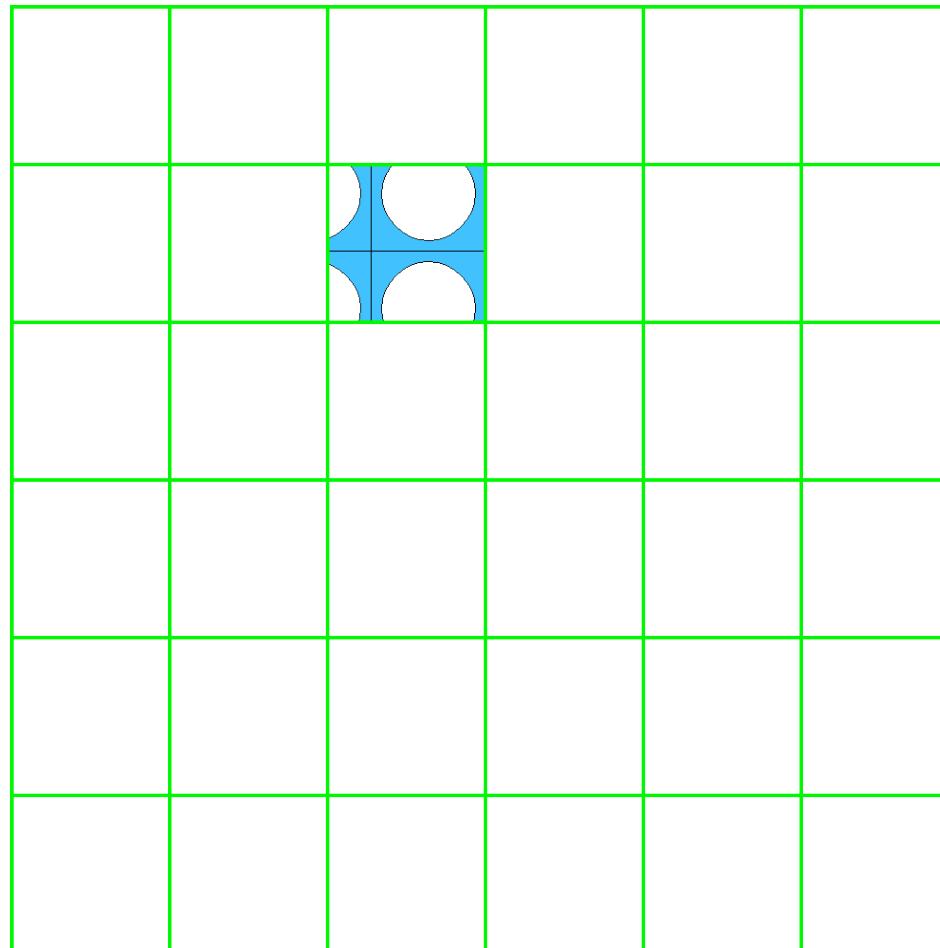
Automated Mesh Single Fuel Mesh



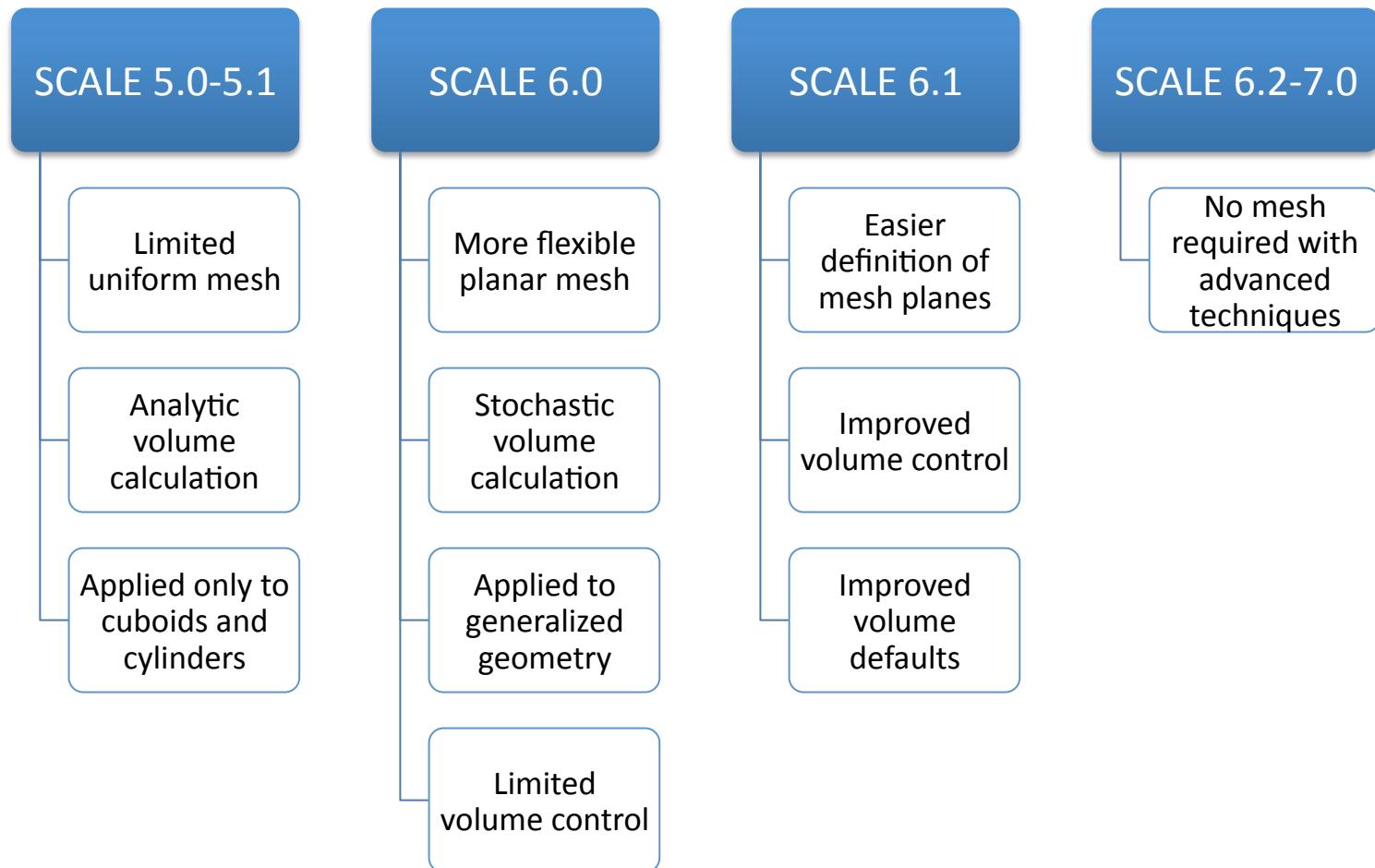
Automated Mesh Single Clad Mesh



Automated Mesh Single Moderator Mesh

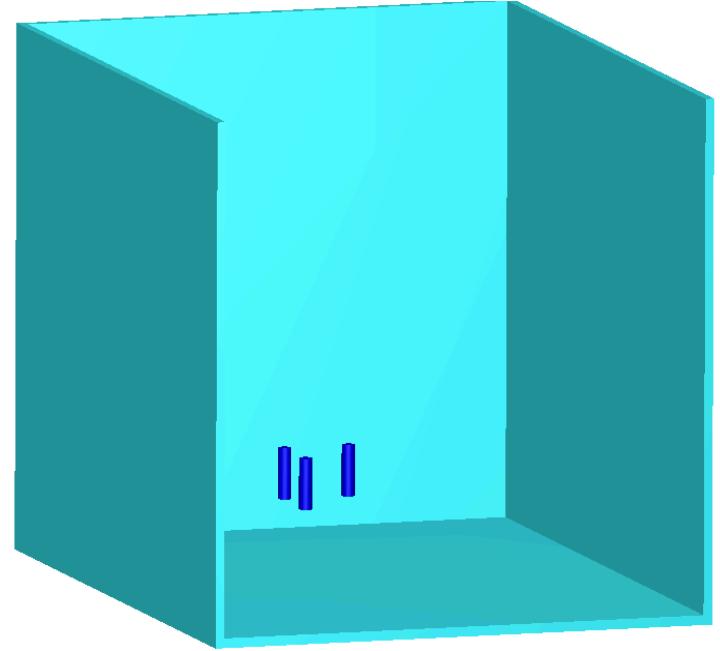


Evolution of TSUNAMI Mesh

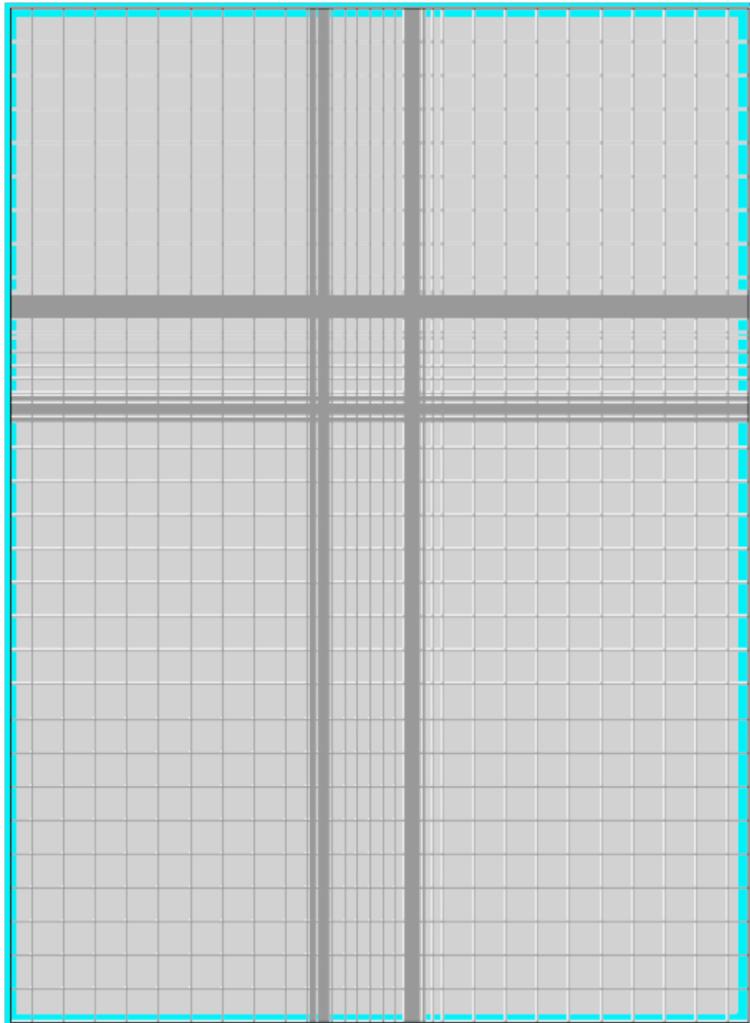


Example: PU-SOL-THERM-014

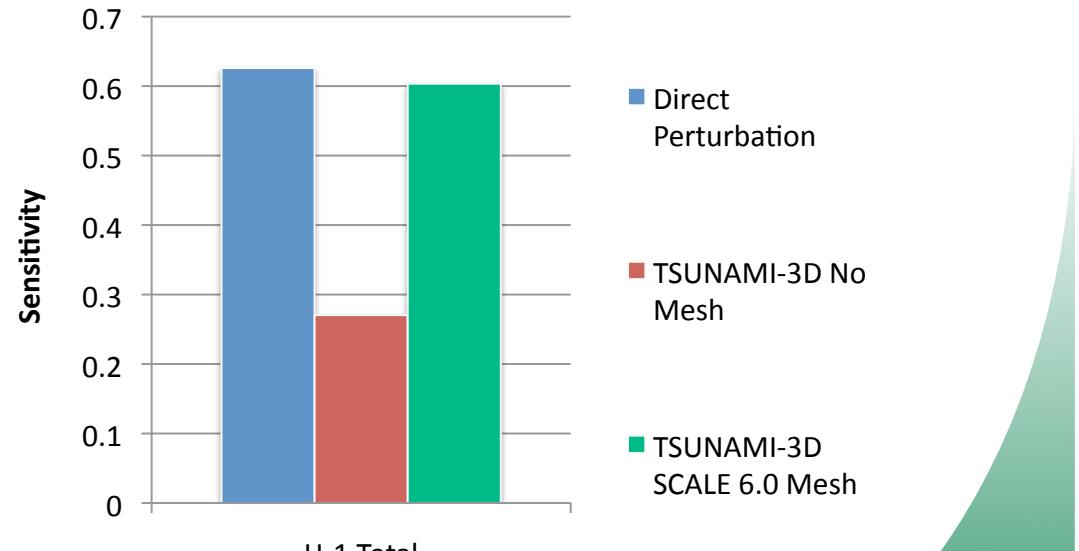
- Pu solution cans (~30 cm)
- Large room (~15 m)
- Desire 3 cm mesh for fissile solution
- Uniform mesh would create ~80,000,000 mesh intervals
- Require ~300 GB of RAM



SCALE 6.0 Planar Mesh



- Mesh refined across fissile solution
- Requires ~140,000 mesh intervals
- ~500 MB of RAM



Planar Mesh

SCALE 6.0

```
read gridgeometry 1
xplanes
-750 -700 -650 -600 -550 -500 -450 -400 -350 -331 -325 -322 -319
-316 -313 -311 -310 -307 -304 -301 -298 -295 -292 -291 -271 -261
-241 -221 -201 -180 -175 -172 -169 -166 -163 -160 -160 -157 -154
-151 -148 -145 -142 -139 -100 -50 0 50 100 150 200 250 300 350
400 450 500 550 600 650 700 750
end
yplanes
-585 -550 -500 -450 -400 -350 -300 -250 -200 -150 -116 -110 -107
-104 -101 -98 -96 -95 -92 -89 -86 -83 -80 -77 -76 -56 -36 -16 4
24 40 43 44 46 49 52 55 58 61 64 64 67 70 84 100 150 200 250 300
350 400 450 500 550 585
end
zplanes
-540 -500 -450 -406 -386 -366 -346 -345 -342 -339 -336 -333 -330
-327 -326 -324 -321 -319 -316 -313 -310 -307 -306 -304 -300 -286
-250 -200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500
550 570
end
end gridgeometry
```

SCALE 6.1

```
read gridgeometry 1
xlinear 30 -750 750
xlinear 15 -331 -291
xlinear 15 -179 -139
ylinear 24 -585 585
ylinear 15 -116 -76
ylinear 15 44 84
zlinear 22 -540 570
end gridgeometry
```

Mesh Volume

- To compute sensitivity coefficients, the volume of each region within each mesh interval must be quantified.
- Beginning with SCALE 6.0, KENO computes the volume through a stochastic sampling process.
- SCALE 6.0 defaults:
 - 5000 points per generation for 1000 generations
- SCALE 6.1 defaults:
 - 5000 points if volume < 13,600 cm³
 - For larger volumes

$$points = \frac{volume}{\ln(volume/5000)}$$

Volume Input

With SCALE 6.1 defaults, PU-SOL-THERM-014 mesh volumes are computed with
~150,000,000 points for 1000 batches

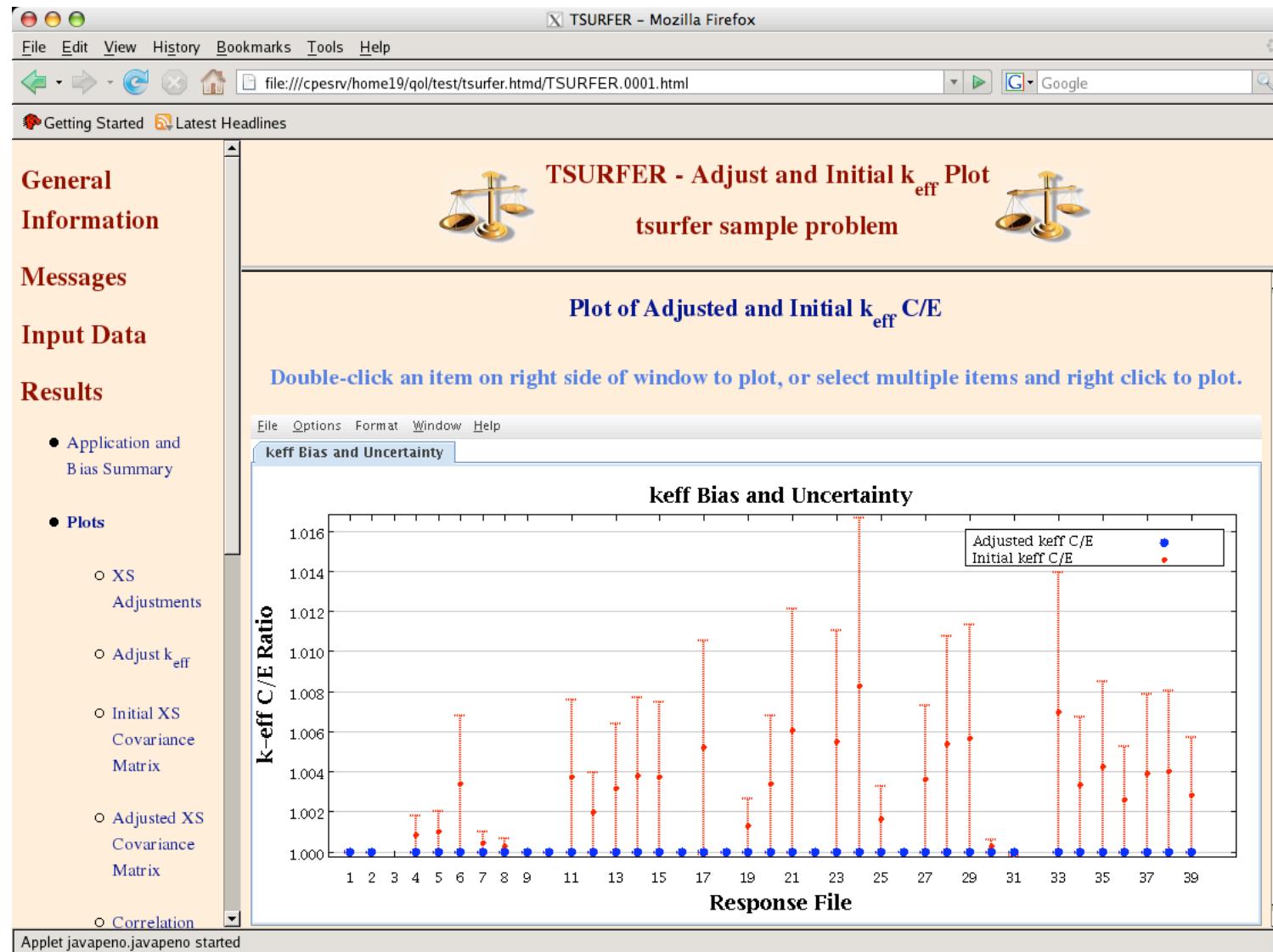
- Input sampling directly:
read volume
points=25000
batches=4000
end volume

- Input sampling density:
read volume
sample_den=0.1
batches=4000
end volume

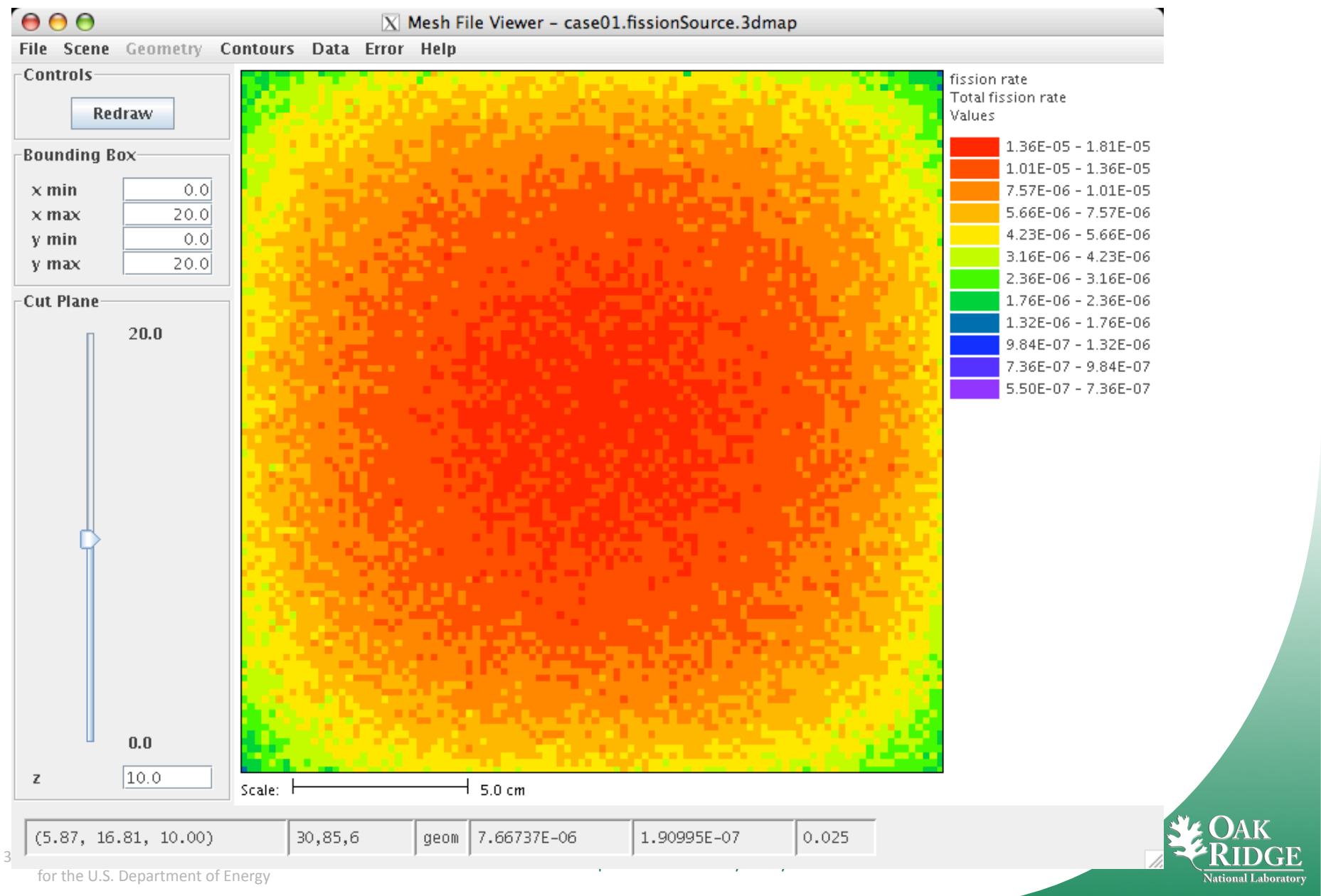
Sensitivity and Uncertainty

- Improved KENO mesh and mesh volume greatly benefits TSUNAMI-3D
- TSUNAMI-2D based on NEWT is introduced
- Generalized perturbation theory calculations in 1D and 2D provide sensitivities/uncertainties due to cross sections for:
 - Flux ratios
 - Reaction rate ratios
 - Few group cross sections, etc
- TSURFER
 - Additional uncertainty edits
 - Additional plots
 - Improved output

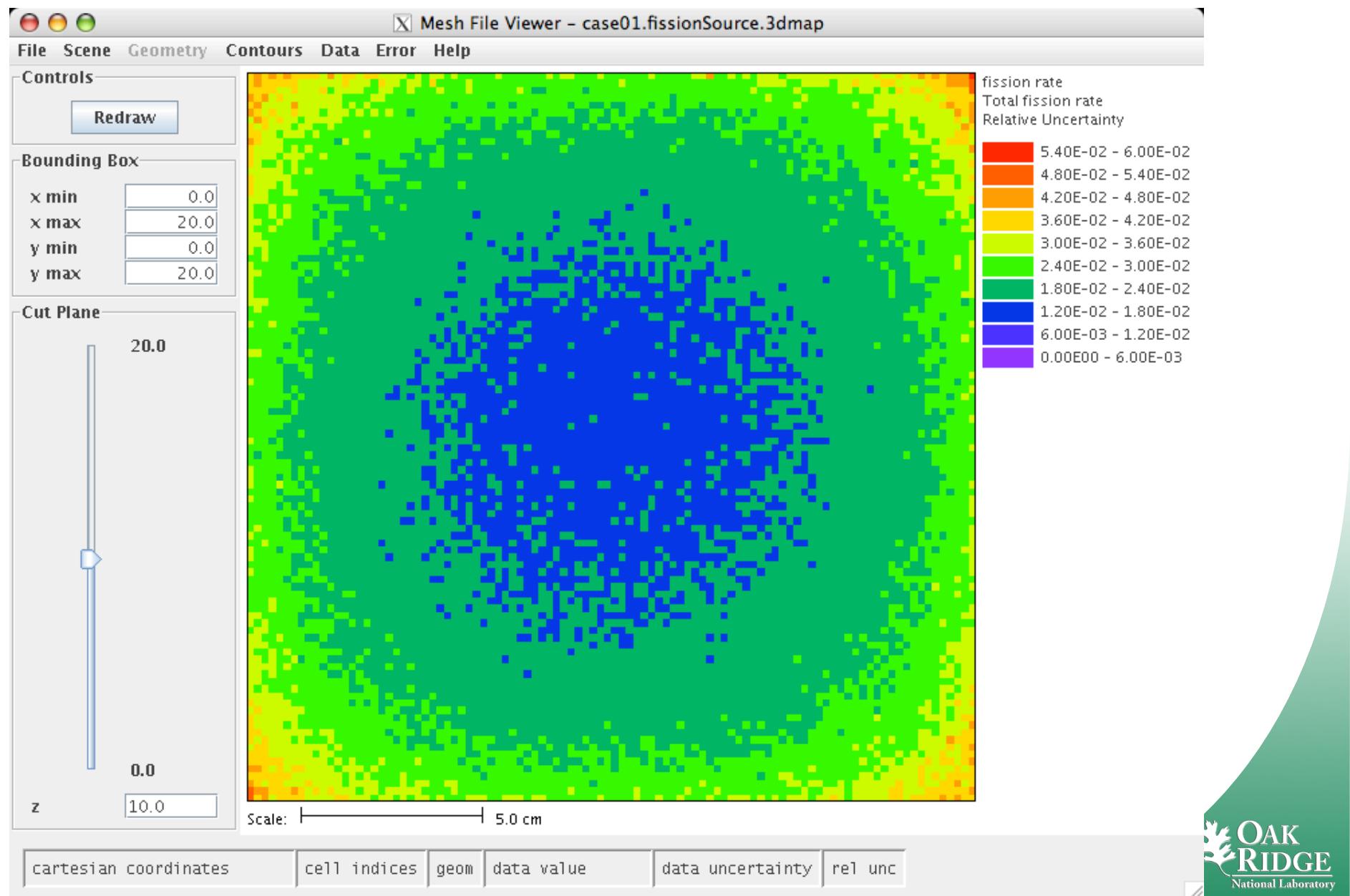
TSURFER Output



Fission Source Viewing



Fission Source Uncertainty



Shielding/Criticality Accident Alarm Analysis

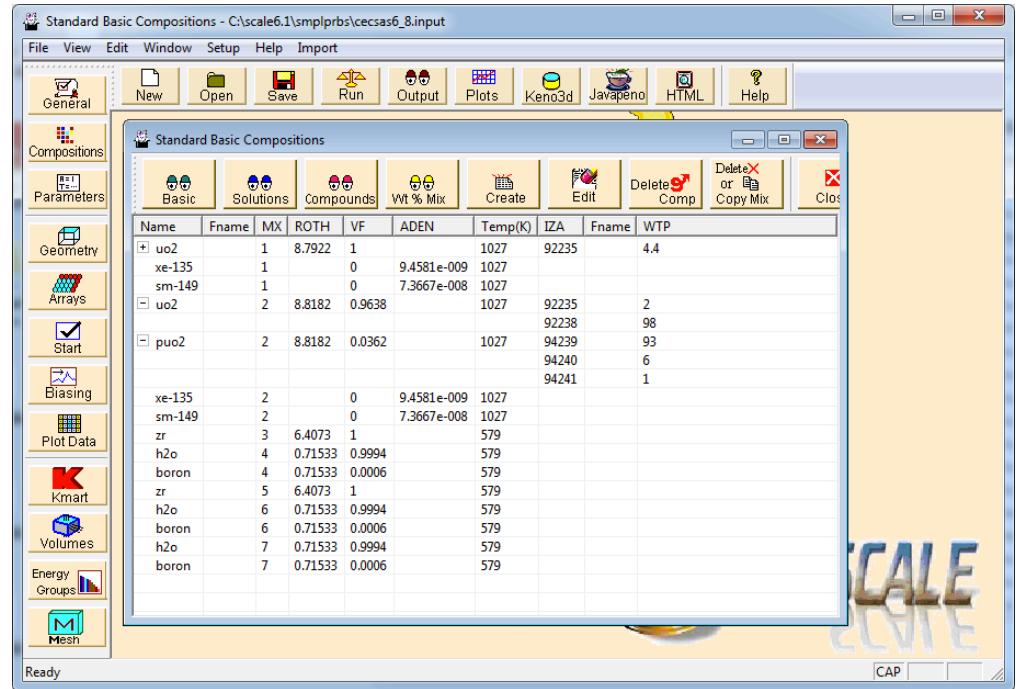
- Numerous enhancements for MAVRIC sequences
 - Multiple sources
 - Spatial variation of sources
 - Energy distributions from ORIGEN or AMPX
 - Macro materials for Denovo calculation
 - Cylindrical mesh grids
 - MAVRIC Utilities

Depletion and Decay

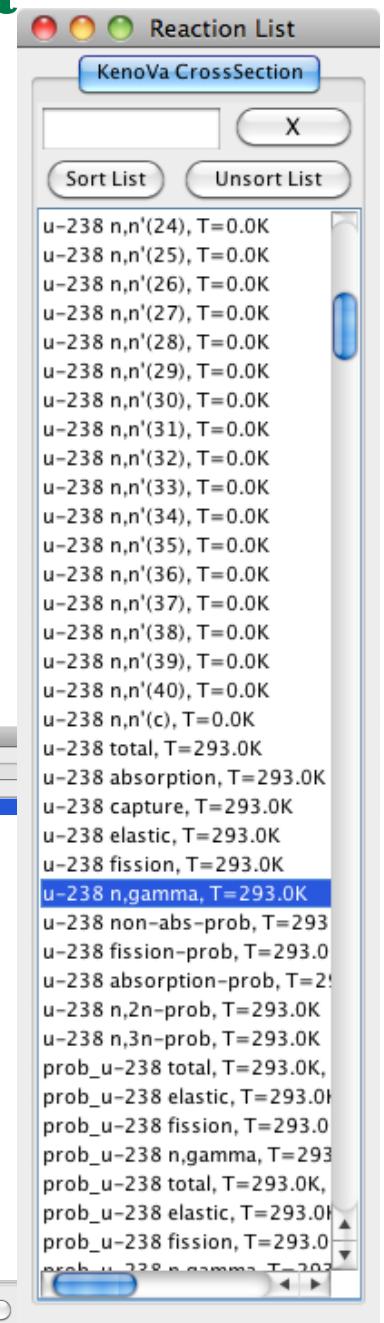
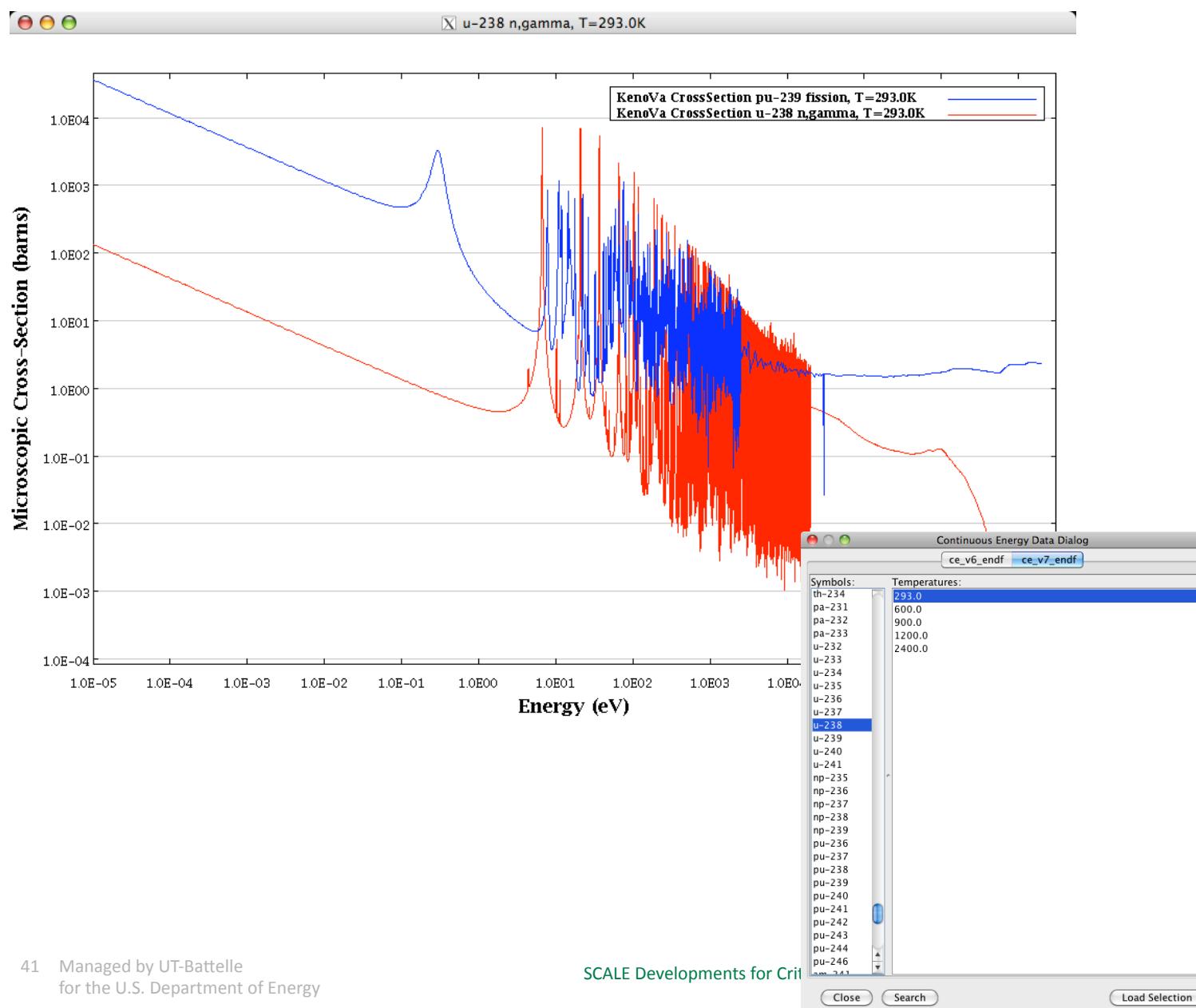
- Important for accurate characterization of burned fuel
- Arbitrary group structures for COUPLE/ORIGEN
- ORIGEN Nuclear Data
 - ENDF/B-VII decay and fission libraries with JEFF multigroup cross sections in many group structures
 - Decay libraries with 2227 nuclides
 - 174 actinides
 - 1149 fission products
 - 904 structural activation materials
- Energy-dependent fission yields
- Cross section transitions from multiple sources
 - JEFF-3.0/A based AMPX libraries
 - AMPX library from SCALE
 - Input from user

Graphical User Interfaces

- **GeeWiz**
 - Substantial improvement in functionality and stability
 - Added code support
 - STARBUCS
 - TRITON
 - MAVRIC enhancements
 - TSUNAMI-GPT
- **Javapeño**
 - CE KENO cross section plotting
 - OPUS plotting (replaces PlotOPUS)
 - NEWT contour plots
 - Custom installer

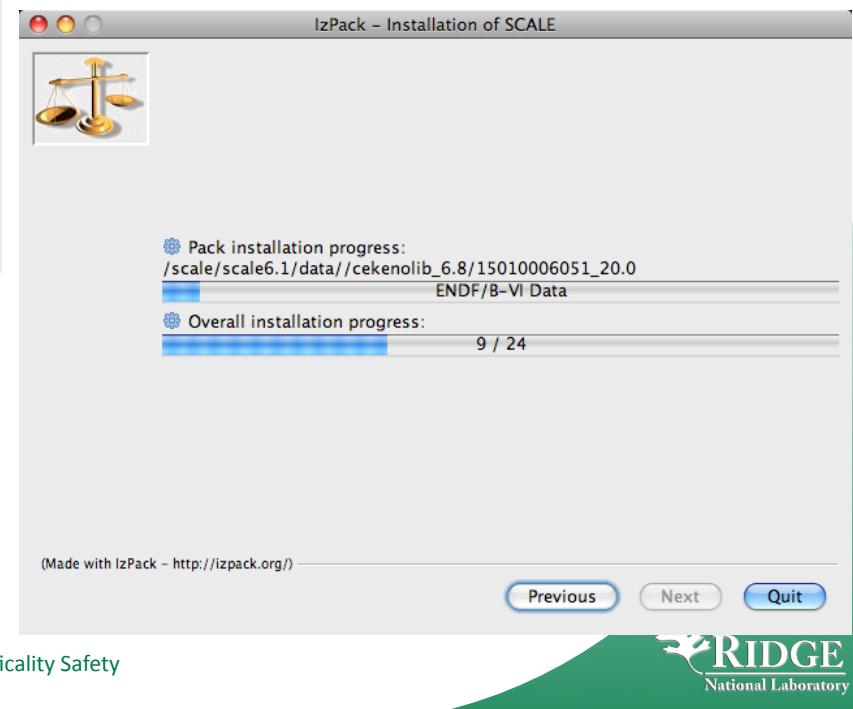
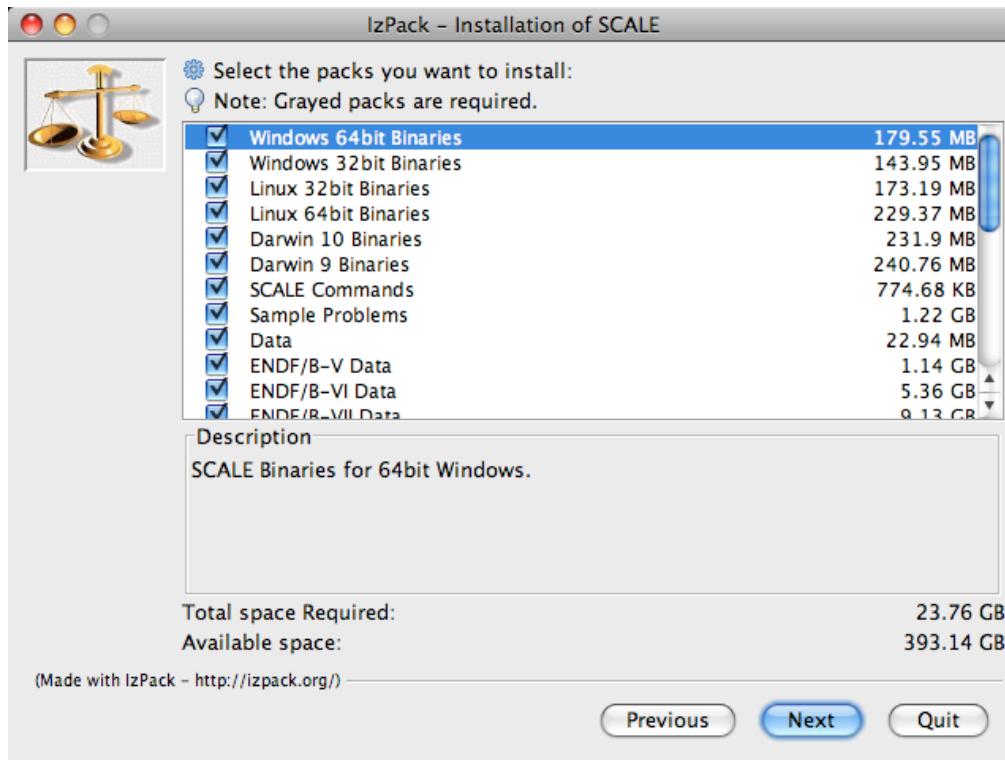


Continuous-energy Cross-section Data Plot

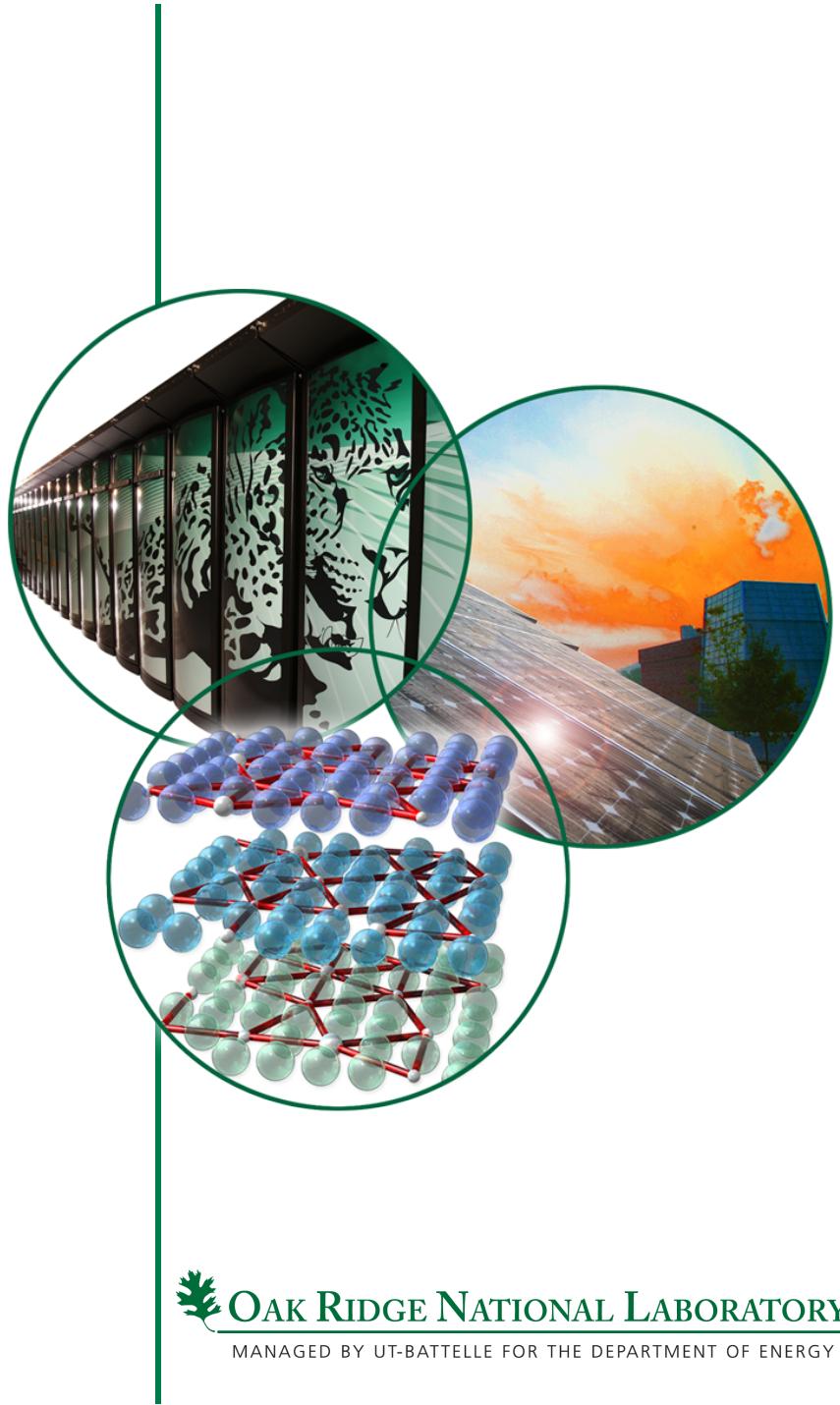


New Installer

- Consistent experience on Linux, Mac, Windows



Infrastructure Modernization



GForge

- Collaborative development environment with web interface.
 - All issues can be identified and tracked.
 - SCALE QA now conducted and tracked within GForge
 - SCALE development ideas and issues are easily tracked to resolution
 - SCALE Help migrated to GForge

The screenshot shows the GForge web interface for the 'SCALE Production' project. The top navigation bar includes links for Home, My Stuff, Search, Projects, Admin, Snippets, and a search bar. A user is logged in as QoI. The main content area features a large logo for 'SCALE' (Simplified Computer Analyses for Licensing Evaluation) with a scale icon. Below the logo, a red banner reads 'Welcome to the Production Version of SCALE'. A sidebar on the left lists various project management links: Summary, Admin, Reporting, Search, Forums, Tracker, Docs, News, Files, Lists, Wiki, SVN, and Build. The central area contains sections for Configuration Control (listing New Module Revision Report, New SCALE Discrepancy Report, etc.), Documentation (Documentation Trackers), and Recent News (No news items found). On the right, there is an Activity chart showing participation over time, a Description section (Production version of SCALE), and a Developer Info section listing names like Robert Lefebvre, Jordan Lefebvre, Kevin Clamo, Brad Rearden, Jay Billings, Thomas Evans, Mark DeHart, Stephen Bowman, Matthew Jessee, Sheila Walker, Sedat Goluglu, Gemma Ilas, Lester Petrie, Mark Williams, Kursat Bekar, Douglas E. Peplow, Debbie Weaver, Scott Mosher, Thomas Miller, Ian Gauld, Don Mueller, Deokjung Lee, Georgeta Radulescu, Joel Risner, David Hartmangruber, and others. At the bottom, a footer states 'SCALE Developments for Criticality Safety' and 'RIDGE National Laboratory'.

Build System

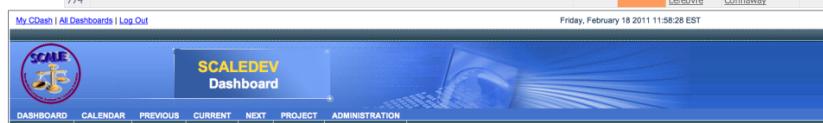
- CMake build system
- Same code and build system will be used on all platforms, Linux, Mac, Windows
- 64-bit Windows build for first time
- Supported platforms:
 - Linux 32- and 64-bit
 - Mac 32- and 64-bit
 - Windows 32- and 64-bit

Regression Testing

- 2010 “SCALE Testing Team”
 - 5 top students recruited to beta test SCALE 6.1
 - ~200 issues identified and corrected
 - developed regression test suite
- Test suite now runs for each code modification
- Nightly build and test
- Web interface “Dashboard” and e-mail reports

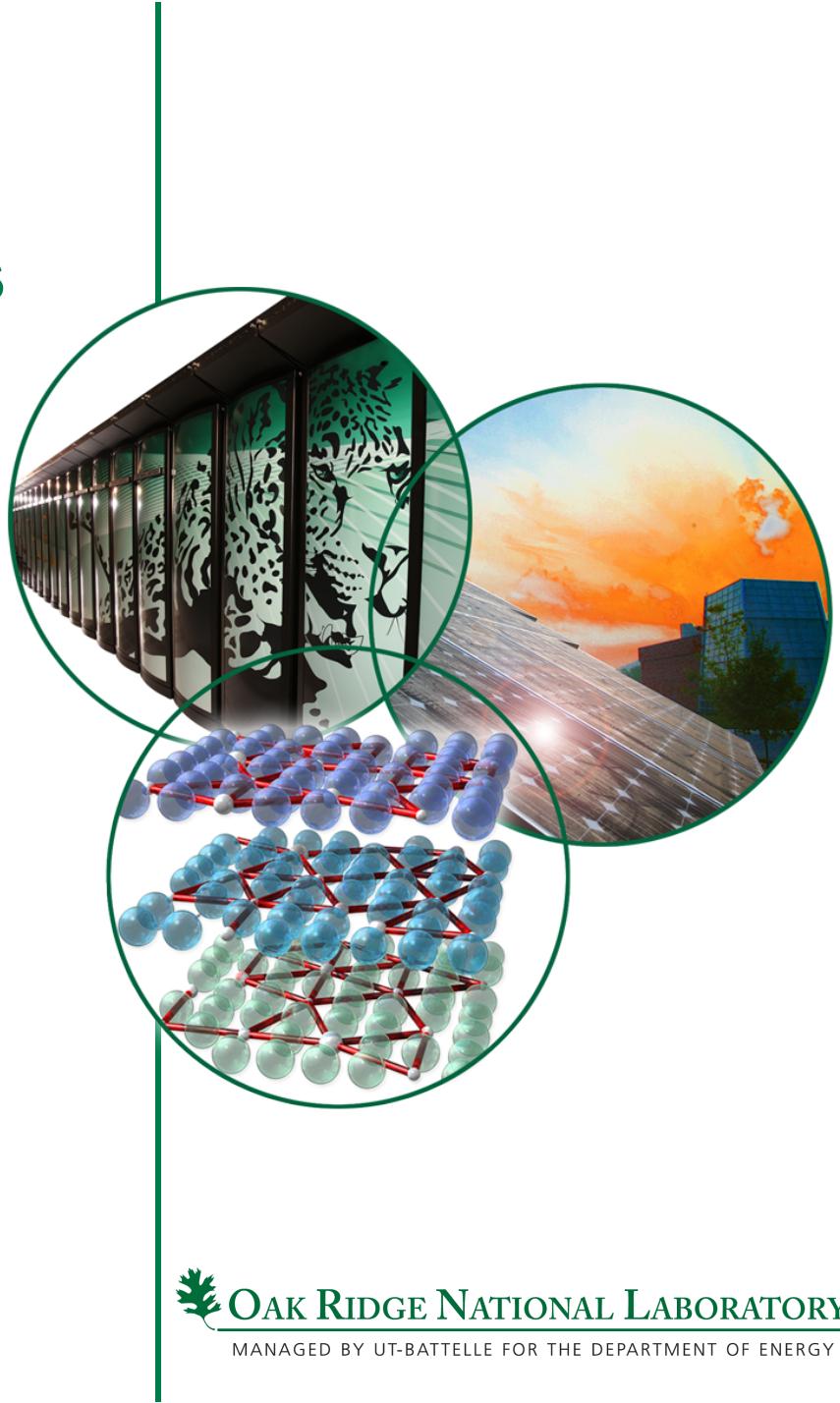


ID	Summary	Delete	Priority	Assigned To	Submitted By	Status	Open Date	Close Date	Last Modified Date
750	GeeWiz6.1 error for example file with ARBM composition	Delete	3	Robert Lefebvre	Heather Connaway	Closed	2010-06-04	2010-06-11	2010-06-11
751	SCALE6 example problems with no global unit	Delete	5	Robert Lefebvre	Heather Connaway	Closed	2010-06-04	2010-06-15	2010-06-15
752	GeeWiz 6.1 error: a blank commentary in the materials block will change the other materials in the PS file.	Delete	3	Brad Rearden	Oscar Lastres	Closed	2010-06-07	2010-09-03	2010-09-03
753	Pn block does not recognize any input after the addition of a non-number ASCII character.	Delete	4	Robert Lefebvre	Oscar Lastres	Closed	2010-06-07	2010-06-09	2010-06-09
754	TSUNAMI/SAMS - Inconsistent sensitivity variance calculations using SCALE6.1	Delete	1	Lester Petrie	Christopher Perfetti	Closed	2010-06-07	2010-08-20	2010-08-20
755	SCALE6.1/TSUNAMI-3D-K5 errors when running array models.	Delete	2	Lester Petrie	Christopher Perfetti	Closed	2010-06-07	2010-07-21	2010-07-21
763	PMC can now handle coupled libraries	Delete	3	Brad Rearden	Brad Rearden	Closed	2010-06-09	2010-07-13	2010-07-13
764	GeeWiz Cone Geometry Radius parameter	Delete	3	Robert Lefebvre	Robert Lefebvre	Closed	2010-06-09	2010-06-10	2010-06-10
768	GeeWiz: Changing Hole Unit updates Media's geometry reference	Delete	3	Robert Lefebvre	Robert Lefebvre	Closed	2010-06-10	2010-06-10	2010-06-10
769	GeeWiz MAVRIC Tally Crash Bug	Delete	1	Robert Lefebvre	Robert Lefebvre	Closed	2010-06-10	2010-06-11	2010-06-11
770	GeeWiz/KENO-VI/TSUNAMI Insert/delete chord buttons are unnecessary for cuboids	Delete	4	Robert Lefebvre	Christopher Perfetti	Closed	2010-06-11	2010-07-01	2010-07-01
771	GeeWiz/KENO-VI incorrect chord value error message	Delete	3	Robert Lefebvre	Christopher Perfetti	Closed	2010-06-11	2010-06-17	2010-06-17
772	KENO3D/KENO-VI cannot display ellipsoids	Delete	4	Robert Lefebvre	Christopher Perfetti	Open	2010-06-11		2010-06-15
774	GeeWiz6.1 Error with FDN Parameter in KENO/VI	Delete	3	Robert Lefebvre	Heather Connaway	Closed	2010-06-11	2010-06-15	2010-06-15



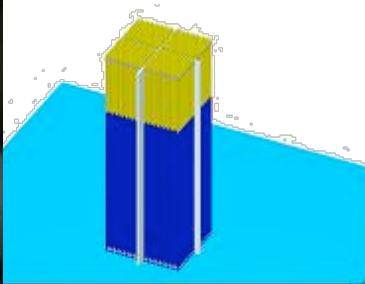
SCALE Developments for Criticality Safety													
Site	Build Name	Update		Configure		Build		Test			Build Time	Labels	
		Files	Min	Error	Warn	Min	Error	Warn	Min	NotRun	Fail	Pass	
node4.ornl.gov	dnyLinux-2.6.39-ELmp-Intel-ONU	9	0.1	0	0	0.2	0	0	2.2	0	2	571	91.6 2011-02-04T00:15:26 EST (none)
Totals	1 Builds	0	0.1	0	0	0.2	0	0	2.2	0	2	571	91.6
Continuous													
Site	Build Name	Update		Configure		Build		Test			Build Time		
node4.ornl.gov	dnyLinux-2.6.39-ELmp-Intel-ONU	4	0.1	0	0	0.2	0	0	2.3	0	2	571	92.9 2011-02-04T19:00:26 EST (none)
node4.ornl.gov	dnyLinux-2.6.39-ELmp-Intel-ONU	1	0.2	0	0	0.7	0	0	4.1	0	3	570	115.5 2011-02-04T16:01:11 EST (none)
node4.ornl.gov	dnyLinux-2.6.39-ELmp-Intel-ONU	9	0.3	0	0	1.4	0	0	9.7	0	3	570	166 2011-02-04T13:56:16 EST (none)
Totals	3 Builds	14	0.6	0	0	2.3	0	0	16.1	0	8	1711	374.4
Experimental													
Site	Build Name	Update		Configure		Build		Test			Build Time		
node4.ornl.gov	gvsLinux-2.6.39-ELmp-Intel-ONU	0	0	0	0	0.2	0	0	2.3	0	22	537	91.5 2011-02-04T13:43:31 EST (none)
Totals	1 Builds	0	0	0	0	0.2	0	0	2.3	0	22	537	91.5

Technical Support Activities

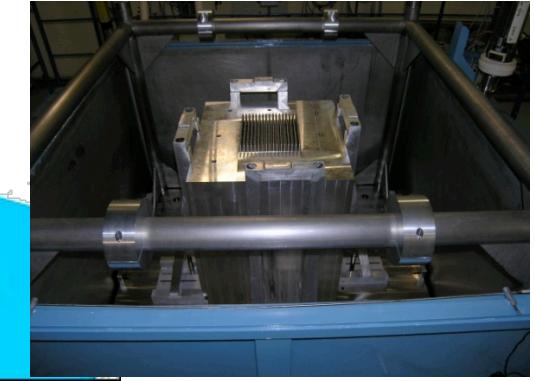
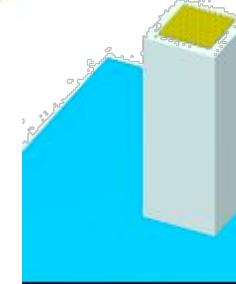


Application of SCALE/TSUNAMI to the Design of MIRTE Reference Experiments

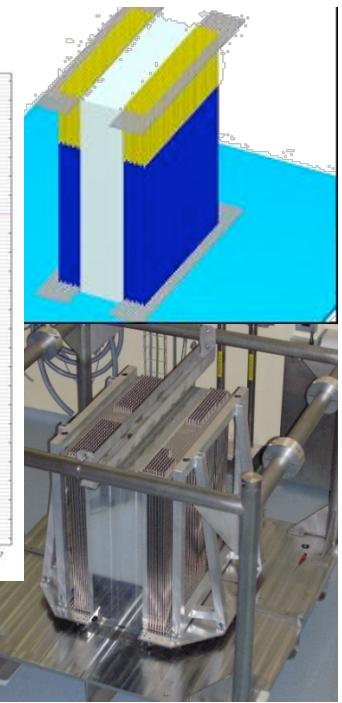
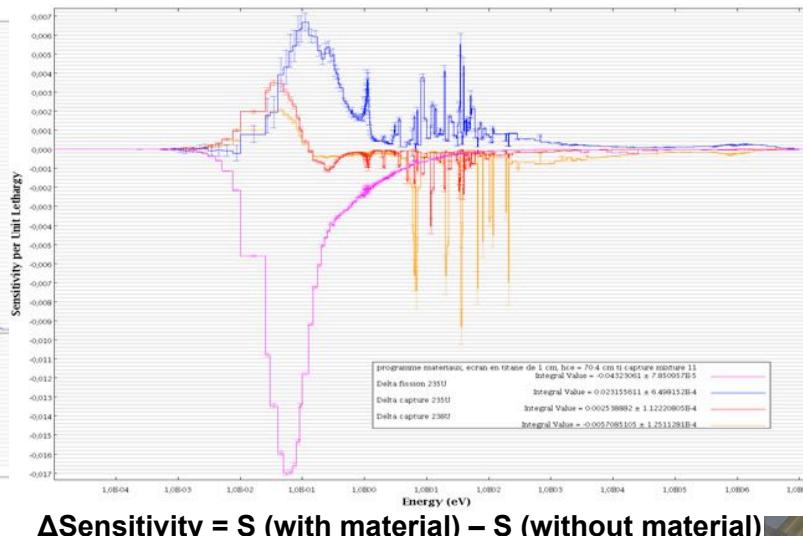
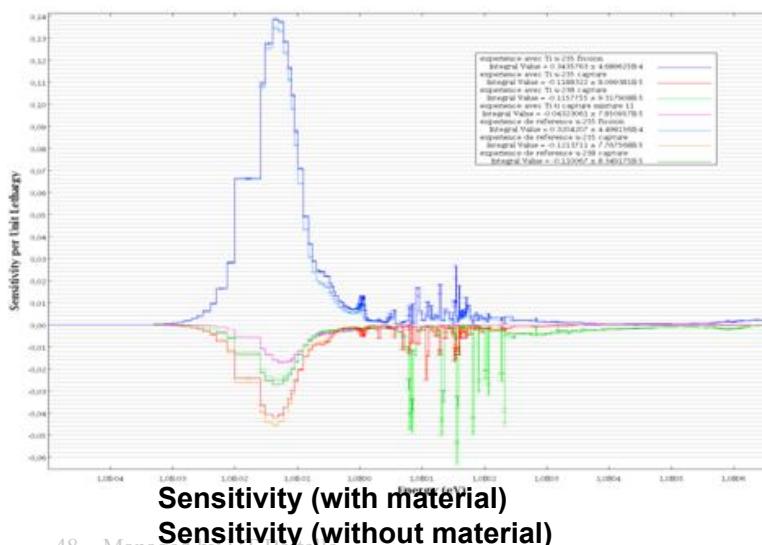
IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE



M_{atériaux} I_{nteraction} R_{éflexion} T_{toutes} E_{paisseurs}



Design of Reference Experiments (Ex: 10 mm Titanium plates)



Collaboration with CEA/Valduc

- October 2009 – Week-long TSUNAMI Training at Valduc
- December 2009 - Detailed SCALE model of CALIBAN developed
- Fall 2010 – Silene CAAS Experiments – More on this later...
- February 2011 – Two-week visit by Valduc staff at ORNL
- ORNL staff member will serve on PhD committee of B. RICHARD

MEMORANDUM OF AGREEMENT FOR AN ARRANGEMENT FOR TECHNICAL COOPERATION

BETWEEN
THE COMMISSARIAT A L'ENERGIE ATOMIQUE
NUCLEAR ENERGY DIVISION
AND THE
UT-BATTELLE, LLC, Management and Operating Contractor of
OAK RIDGE NATIONAL LABORATORY

BACKGROUND

This Memorandum of Agreement (Agreement) is made between the Nuclear Energy Division (DEN) of the Commissariat à l'Energie Atomique (CEA) of the Government of France and UT-Battelle, LLC (UT-Battelle), the management and operating contractor of the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) located in Oak Ridge, Tennessee, United States of America (U.S.A.). UT-Battelle (hereafter referred to as ORNL) enters into this Agreement pursuant to Prime Contract No. DE-AC05-00OR22725 with DOE.

CEA and ORNL (hereinafter referred to as the 'Participants') are leading institutions of nuclear research and development (R&D) for their respective countries and desire to promote and develop closer scientific and technological cooperation in the development and application of nuclear energy for peaceful purposes.

PARAGRAPH I – PURPOSE

The Purpose of this Agreement is to strengthen the technical cooperation of the two Participants by:

- A. Promoting collaboration between US and French research organizations to:
- B. Promoting scientific breakthroughs in nuclear fission science and technology;
- C. Promoting and maintaining each nation's nuclear science and engineering infrastructure and related research facilities at the forefront of technology.

PARAGRAPH II – FIELD OF COOPERATION

Cooperation includes, but is not limited to, the following areas:

- A. Development of instrumentation and irradiation devices for testing materials and fuels in experimental reactors;
- B. Development of a non-contaminating processes for actinide fuel processing and fabrication;

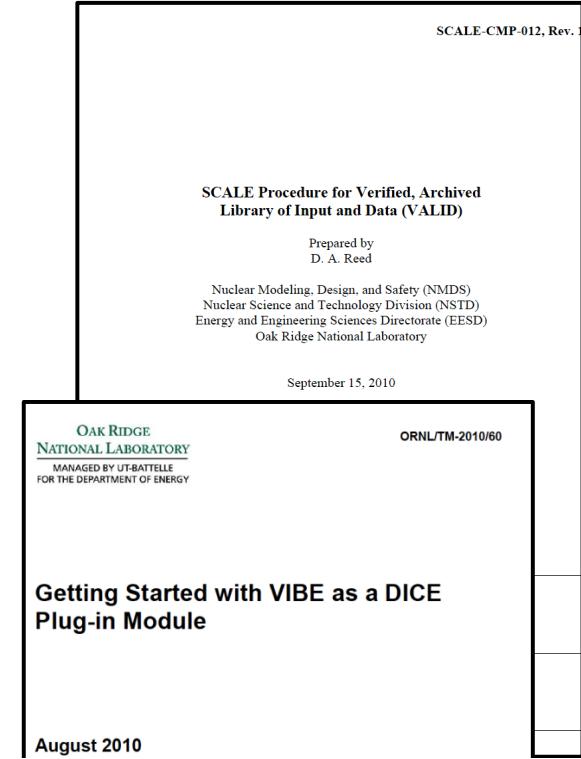
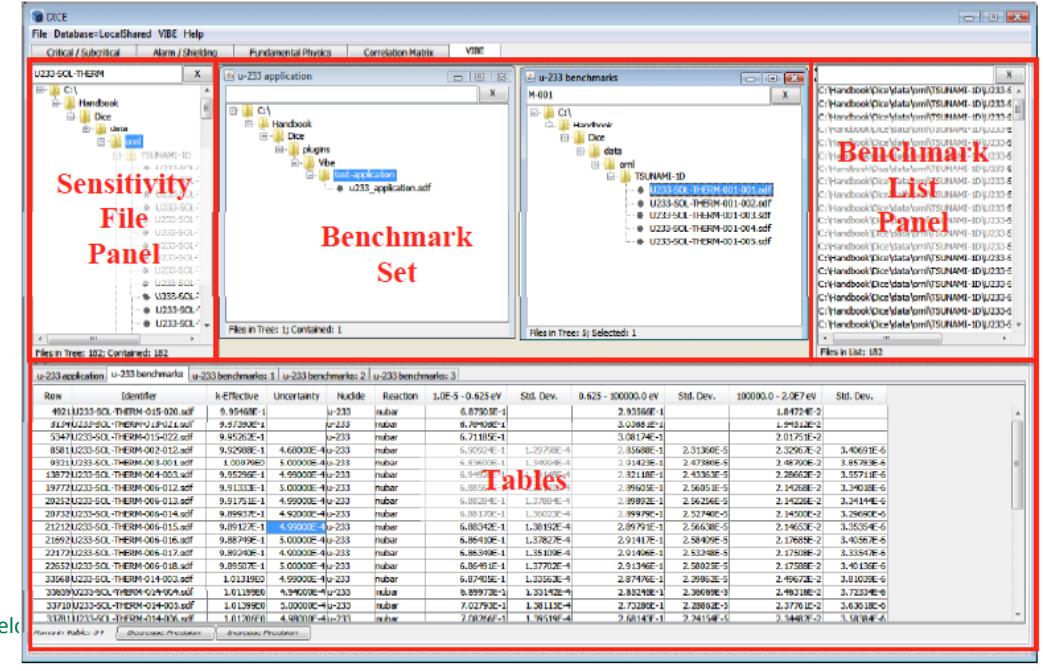
MOA/I/B/20023

1



ICSBEP, Sensitivity Data, VIBE

- ORNL staff serving on ICSBEP Task Team
- Ongoing interaction with DICE developers
- Integrated VIBE into DICE for 2010 ICSBEP distribution
 - Supported new DICE database format, and preserved backwards compatibility with 2008, 2009 data formats
 - Published “Getting Started” Guide
- Provided QA’d SCALE inputs and sensitivity data files for 78 ICSBEP benchmark models



OECD/NEA Working Party on Nuclear Criticality Safety

- **Leading role in expert groups:**
 - Uncertainty Analysis for Criticality Safety Assessment
 - Advance Monte Carlo Techniques
 - Burnup Credit Criticality
 - Assay Data of Spent Nuclear Fuel (chair)

SCALE 6.1 Schedule

- Beta release provided to:
 - RSICC
 - OECD/NEA Data Bank
 - ~25 external testers
- Final modifications under review
- Documentation in editing
- Release expected in late March 2011

Questions?



Brad Rearden
SCALE Project Leader
scalehelp@ornl.gov